PB-218 644

THE USE AND EFFECTS OF PESTICIDES FOR RANGELAND SAGEBRUSH CONTROL

Alvin R. Hylton, et al

Midwest Research Institute
Kansas City, Missouri

May 1972

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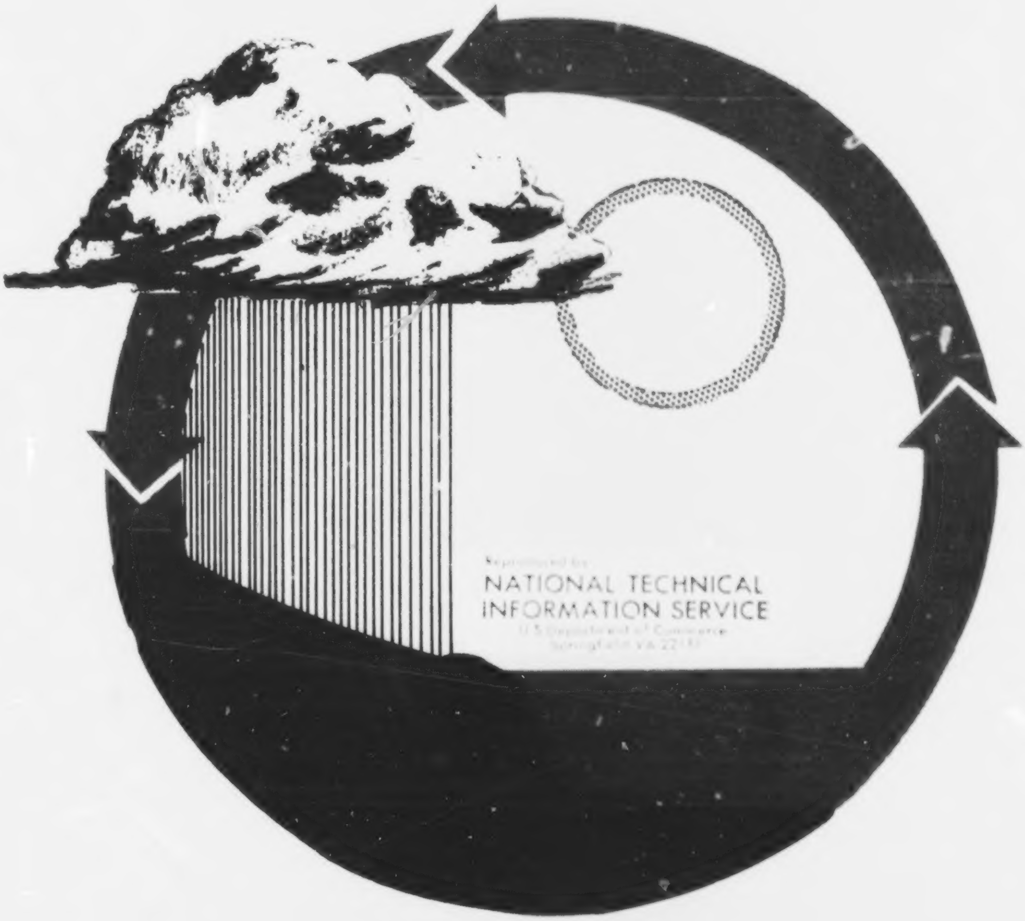

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THE USE OF PESTICIDES FOR RANGELAND SAGEBRUSH CONTROL

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THE USE AND EFFECTS OF PESTICIDES FOR RANGELAND SAGEBRUSH CONTROL

This study is the result of Contract No. 68-01-0128 awarded by the OWP, as part of the Pesticides Study (Section 5(ℓ)(2) P.L. 91-224) to Midwest Research Institute.

A. R. Hylton, Project Leader
G. R. Savage, Program Coordinator
The EPA Project Officer was Charles D. Reese, Agronomist

ENVIRONMENTAL PROTECTION AGENCY
Office of Water Programs
Applied Technology Division
Rural Wastes Branch

May 1972

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SUMMARY

Sagebrush infests about 270 million acres of land in the United States. Large areas of this land are potentially suitable as rangeland for both livestock and various species of wildlife. Big sagebrush, Artemisa tridentata, is the most important species of sagebrush, occupying about 53 percent of the total sagebrush areas. Aerial treatment of sagebrush with 2,4-D herbicide has proven to be effective, economical and practical. The most generally used formulation is the butyl or isopropyl ester of 2,4-D. Soil erosion usually is not increased by spraying sagebrush, and indications are that the control of sagebrush on drainage areas may increase water flow from those sites. When properly used, 2,4-D is not considered to be toxic to man, domestic animals, game or fish. There are a number of microorganisms that can degrade 2,4-D and the herbicide does not accumulate in the soil. Forbs and browse, including sagebrush, are important as food for various species of wildlife that inhabit the rangelands. A reduction of certain forbs on summer ranges could adversely affect antelope, sage grouse, mule deer, whitetail deer, elk, and possibly moose. It is highly unlikely that the use of 2,4-D for controlling sagebrush presents a hazard as a water contaminant. Analyses of water samples from the Western United States show the amounts of 2,4-D when present, to be far below the concentration permissible in public water supplies. Methods other than herbicide spraying which have been employed to control sagebrush are more expensive. Federal and state laws and regulations concerning the use and sale of pesticides within the study area were evaluated.

FOREWORD

This Final Report presents the results of a case study of the effects of herbicide use for rangeland sagebrush control. This project was a part of a pesticide study authorized by Section 5(1)(2) of P.L. 91-224 to conduct a series of studies of the impact of different types of pesticide use on the natural environment.

The work reported covers the period 25 June 1971 to 15 January 1972. Dr. Alvin R. Hylton, Senior Environmental Scientist, served as Project Leader, and Mr. George R. Savage, Senior Biologist, was Program Coordinator.

Appreciation is expressed to the outstanding consultants who made available their time, knowledge, and experience to this project. Without the contributions of the following individuals, this report would not have been possible:

Dr. A. D. Allen, Toxicologist, Consultant to MRI.

Dr. Harold P. Alley, Professor of Weed Control,
University of Wyoming, Laramie, Wyoming.

Mr. John L. Artz, Extension Range Specialist,
University of Nevada, Reno, Nevada.

Dr. Walter L. Gould, Associate Professor of Agronomy,
New Mexico State University, La Cruces, New Mexico.

Mr. F. Farrell Higbee, Executive Director, National
Agricultural Aviation Association, Washington, D.C.

Dr. Norman G. P. Krausz, Professor of Agricultural Law,
University of Illinois, Urbana, Illinois.

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I. INTRODUCTION

It has been estimated that sagebrush occupies about 270 million acres of land in the United States.[1/] Since most of this land lies within the Western Range, vast areas of potentially productive rangelands are relatively useless because of sagebrush infestations. These woody plants compete with more desirable vegetation, prevent growing and grazing of grasses, and hamper the movement of livestock. Because of these large concentrations of sagebrush, lambs and calves often stray and become lost,[2/] since heavy sagebrush stands provide excellent cover for predators (e.g., coyotes). Because of these factors, western rangelands now support considerably smaller numbers of livestock than they would otherwise be able to support.

These sagebrush-infested grasslands and rangelands of the western United States are dominated by a cover of undesirable species of plants. It is well known that one of these plants, big sagebrush, is a very inefficient user of water and highly drough-resistant; it produces a minimum of palatable forage for livestock and game animals. It is abundant in watersheds in every state in the West. Until recent years, it was believed impractical to superimpose any management practice on sagebrush lands because costs of improvement were prohibitive in relation to the possible gains in return. With the advent of selective herbicides, chemical removal of sagebrush has revolutionized the management procedures which can be applied to sagebrush-dominated lands.

Many methods have been used to eliminate sagebrush and to clear land, but in recent years the application of 2,4-dichlorophenoxyacetic acid (2,4-D) herbicide has emerged as the control method of choice. Spraying of 2,4-D has proven to be an effective, economical, and practical sagebrush control measure.[3-6/] However, there has been concern about possible adverse environmental effects resulting from the large-scale use of this herbicide. Detrimental effects that have been suggested include disruption of faunal habitats, endangerment of certain species, modification of food chains, promotion of soil erosion, laterization and siltation, and increased turbidity of streams and lakes.[6-13/] The purpose of this report, then, is to present factual information on these and other effects, both adverse and beneficial, which may be caused by the use of herbicides in controlling sagebrush.

A general description of the sagebrush-growing areas of the western United States, the history of herbicide use in the study area, application techniques, herbicide formulations, and alternate methods of sagebrush control are presented in the first five sections of this report.

In the following sections, a discussion and analysis of the broad environmental effects of 2,4-D are given. Areas included are the consequences of 2,4-D use on biotic factors (flora and fauna), abiotic factors, the aquatic environment; and the toxicity and hazard of 2,4-D to animals and man. A discussion of the legal aspects concerning the use of herbicides also is given. Finally, conclusions and recommendations are made about the use of this herbicide to control sagebrush.

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II. A GENERAL DESCRIPTION OF THE SAGEBRUSH GROWING LANDS OF THE WESTERN UNITED STATES

A. General

Sagebrush is native to a vast area of western North America. It occurs from Montana and western Nebraska to British Columbia and California. The term "sagebrush" includes a variety of shrubby species of the genus which grow on the mountain slopes and particularly on semiarid plains, mainly between 1,500 ft to 10,000 ft altitude, where they are often the most conspicuous feature of the vegetation. More than one-half of the total acreage of this sagebrush is located in Wyoming, Idaho, Montana, and Nevada.[1] The remaining, approximately 47 percent, is spread throughout Utah, Colorado, New Mexico, Arizona, California, Oregon and Washington. At least 11 species of Artemisia grow in the western United States, and cover approximately 270 million acres. By far the most important species is the "big sagebrush" (*Artemisia tridentata*), which covers about 144 million acres or 53 percent of the sagebrush areas.

The sagebrush study region investigated in this report includes 11 western states (Washington, Idaho, Montana, Wyoming, Colorado, Utah, Oregon, Nevada, California, Arizona and New Mexico) and encompasses the highest, driest, and most rugged regions of the United States. No other part of the nation has so many different and dramatically unique physical and climatic characteristics as this region, yet, when viewed in terms of economics and human livelihood, many of these differences merely add up to the same conclusions, that this land has a limited potential for supporting a large human population or large numbers of animals.

In broadest terms, the region is divided into two major parts: the Great Plains, situated east of the Rocky Mountains, and the Rocky Mountain and Intermountain Plateau areas located between the Great Plains in the east and the Sierra Nevada Mountains in the west (Figure 1).

B. The Plains of Eastern Montana, Wyoming, Colorado, and New Mexico

General Characteristics: In these plains agriculture is by far the leading and most basic industry. Except for petroleum and gas fields and scattered coal mines, agricultural resources are the foundation upon which this region's economy is built. However, these agricultural resources are limited.

Because rainfall is scarce, less than 20 in., farmers must grow such drought-resistant crops as wheat, barley, and sorghum. Moreover, rainfall is highly variable, and the farmer must be prepared to face repeated failure or part-failure in order to reap the benefits of better years.

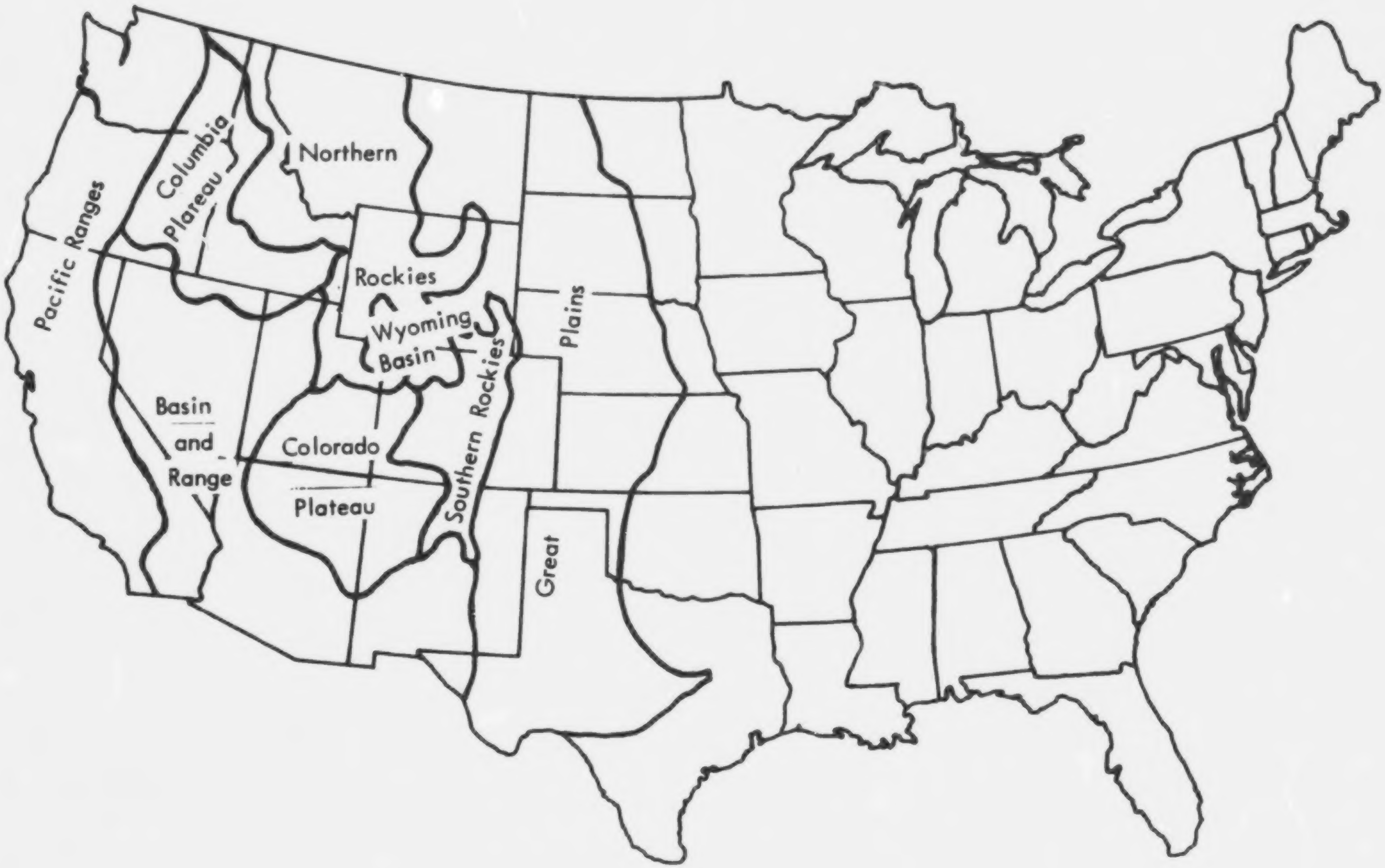
Pacific Ranges
Columbia Plateau
Northern
Rockies
Wyoming Basin
Basin and Range
Colorado Plateau
Southern Rockies
Plains
Great

Figure 1 - The General Physiographic Provinces Located in the Study Region (After Lobeck, 1932 Rev.)

A large percentage of the farmland is not plowed, but instead is allowed to remain in pasture or grazing land. The result is that there is a much larger supply of forage feed which stimulates a great cattle and sheep ranching industry than of feeds for fattening.

Because of lower rainfall, rougher topography, and short growing season, the grazing land and croplands yield much less production per acre than do farms in the Corn Belt. As a result, to yield a respectable livelihood, farms must be very large in size.

Strenuous efforts have been made, and are still continuing to be made, to bring water to these dry lands. Irrigated tracts are found along the river valleys, along the margins of the mountains, and even at spots where water can be lifted to the surface by pumps.

Physiography: More specifically, the Plains Region is an elevated plateau that slopes gradually upward to the west. In most parts, the surface is almost monotonously flat and treeless, but there is much broken and rough land too. The principal rivers--the Canadian, Cimmaron, Arkansas, Platte, Yellowstone, and Missouri River and their tributaries--have eroded the lands paralleling their course to such an extent that much of it is very rolling and broken. Isolated mountains, high hills, and mesas in eastern Montana, Wyoming, Colorado and New Mexico add to the quantity of the land that does not follow the characteristic tableland patterns.

Mineral Resources: Mineral resources are very limited in this region, with fuels being the most important. Coal is mined in Colorado, Wyoming and Montana, but the volume of production is small in comparison with output in other U.S. regions. Petroleum and gas resources are also secondary in comparison to those fields in central Texas, Oklahoma and the Gulf Coast. Deposits of lignite, low-grade coal, and some uranium, are found in the region, but they are minor compared to the mineral resources of the Rocky Mountains.

Soils and Climate: The soils are moderately fertile. As a general principle, moisture, not soil, is the limiting factor in crop production in the region. Except for the rougher lands mentioned above, and sections where the soil is sandy, the land could be tilled and the soil rendered highly productive if there were sufficient moisture.

Moisture-laden winds precipitate their moisture on the western slopes of the Rocky Mountains. When they cross the Great Divide, they become warm and dry and furnish very little rainfall to the region. The average rainfall, in the range of 12 to 16 in/year, is uncertain and variable, and it is not uncommon for some areas to receive one-half or twice its annual rainfall.

Another major agricultural problem is soil erosion. Where the soil is floury and light, it blows easily in the high winds, which are common. Damage can also result from water erosion in the unusually wet years or torrential rains that occasionally occur.

Animal Ecology: Among the larger and most important animals in this area are the pronghorn antelope. The coyote is a marauder on sheep and game. Prairie dogs, rabbits, gophers, snakes and lizards thrive because they require but modest quantities of food and water, and because they avoid hazardous conditions by remaining much of the time underground. Grasshoppers and locusts in dry years are plentiful.

The Wyoming Big Horn Basin: Characteristic of this region is the Big Horn Basin in Wyoming. Because it is adjacent to the Rocky Mountains, much of the land is hilly, broken, and rough, and much of the soil is stony or has a clay composition. Since the basin is almost completely surrounded by mountains, there is only a scanty rainfall. There is scarcely enough rain to make the rangeland worth grazing in many years, and far too little for dry-farming in most parts. There are no forests, only a few mines, and a modest scattering of oil fields. Nevertheless, the population of the Big Horn Basin is prosperous and lives at a level of comfort that surpasses that of the plains located to the east.

The technological secret of this success has been irrigation. Streams descending from the mountains have been tapped, and long strips of irrigated land extend out into the flatlands. Large farms and raches are based on the principle of modest returns from vast tracts of land, averaged out over a period of years.

Outside the strips that have been transformed by irrigation, some of the most adverse agricultural conditions in the entire region are found.

C. Rocky Mountains and Intermountain Basins

Introduction: The majority of the sagebrush study region is comprised of mountains and intermountain basins. Characteristically this region is composed of rugged mountains that are too high, rocky, barren, and steep for settlement, and vast deserts too hot and dry to support more than a token amount of plant life. As a result of these conditions, this region has a small population.

Interspersed throughout this generally unfavorable setting are plateaus, valleys and river bottoms that have enough rainfall and sufficiently good soil to produce drought-resistant cereal and other crops, or which can be irrigated to produce a great variety of cash crops and livestock feed.

In many sections the soil and other conditions for agriculture are ideal, except for a deficiency of moisture. Huge irrigation and reclamation projects have converted several such places into highly productive agricultural garden spots, including the Snake River Plains of southern Idaho, the Great Salt Lake in Utah, the Gila River and Salt River of Arizona and the Columbia Basin in Oregon and Washington.

In addition to scattered rich agricultural areas, large deposits of minerals exist. A major share of the nation's supply of copper, lead, silver, gold, zinc, tungsten, and other minerals is mined here at widely scattered points.

Because of more limited rainfall, the forests of this region are not so dense and quick-growing as in the Pacific Northwest. Even the semibarren desert wastes, if not grazed too heavily, are able to support livestock.

Major Physical Characteristics: When viewed in economic terms, this vast area has four major physical regions, described in the following paragraphs.

The Rocky Mountain Ranges: This area is a tangled mass of peaks and ranges extending from Montana, Idaho, Wyoming, Colorado to New Mexico. High ranges with deep valleys between them are characteristic of the region. At medium altitudes, on more gentle slopes, forests grow, and several scattered wider valleys can be farmed.

Western Desert, Semidesert and Mountains: This area comprises the Great Basin, Colorado Plateau and Columbia Plateau territory west of the Rocky Mountains. Scattered mountain ranges are interspersed with broad prairie-like and nearly level stretches of desert or semidesert land, or eroded plateaus that also are very scantily vegetated. All of Nevada, southern, western and eastern Utah, northern Arizona and southeastern Oregon and eastern California fall into this region.

The Snake River and Wasatch Front: This area is an oasis wedged in between the Rockies and the desert. It is a man-made region; water from mountain streams has been diverted to irrigate the desert and to support growing commerical and industrial cities.

The Trans Pecos and Southern New Mexico: This area is a southward extension of the Rocky Mountains. Here the ranges are not so high, and are more scattered with broader valleys between. Because of less rainfall, even on the upper slopes, this is semiarid county where the lower slopes and valleys are covered only with brush and grass.

Mineral and Water Resources: Mineral deposits of a very great variety may be found at many different locations in the region. Copper deposits in Montana, Utah, New Mexico and Arizona are most important; uranium finds on the Colorado Plateau and in the Wyoming Basin somewhat less so. Silver, lead and zinc are also found.

Moisture falling on the mountain slopes is a valuable resource for generating electrical power and for irrigating the desert lands. Limited urban development and economic growth have resulted in large part from the damming of the mountain stream and rivers for these purposes. The economy of much of the region rests on the ability to control and exploit water resources.

The region is drained primarily by the Snake and Colorado Rivers and their tributaries, and by streams that have no outlet. Instead of draining moisture to points outside, these streams merely develop temporarily after a rain and flow across the desert plateaus to low basin-like depressions where the water is absorbed or is evaporated into the dry hot temperature. Shortly after a storm, the stream and the lake into which it empties have both dried up. After being repeated for many centuries, this process has caused large quantities of mud and silt to be washed from the mountains into the flats, and (together with wind erosion) is responsible for the level terrain between most of the ranges, particularly in the Great Basin, and for an accumulation of saline and alkaline chemicals in the soil, which destroy plant life.

Agriculture: The majority of the agricultural enterprises are characterized by migratory grazing of large herds of sheep and cattle. The amount of forage available per acre is so small that herds must be moved to prevent overgrazing and to take advantage of seasonal growth. The animals may be driven to upper mountain pastures in the summer and wintered in the valleys. Two of the major problems faced by ranchers are water for their cattle and growing sufficient feed for the winter months when the range is either covered with snow or provides inadequate grazing. Wild hay, sorghum, barley and irrigated forage crops are grown to relieve this problem.

Irrigated farming, another major agricultural enterprise, is important in growing cash crops of sugar beets, potatoes, vegetables and fruits. Where soil conditions are favorable and water can be diverted from streams, obtained from artesian wells, or pumped from drilled wells, this type of agriculture is found. In some places these developments are the result of very large reclamation projects, and have involved a complete transformation of the desert. In other instances they are little more than exploitation of a small stream to irrigate a narrow strip of valley soil, or pumping water to irrigate an isolated tract. Although a small percentage of the land area is irrigated cropland, roughly one-third of all farm income is derived from the cash sale of crops grown on irrigated land. Dry-land farming, dairy and poultry farming are definitely secondary types of farming in the region.

Climate and Weather: The great physical varieties found in this region affect the climate in the region. While certain generalizations are possible, relief exerts the main control upon temperature and precipitation, and overall descriptions of climate become impossible.

The eastward flowing winds precipitate a liberal amount of moisture upon most of the western slopes of the Rockies and Sierra Nevada Range, and even upon the upper slopes of the lower ranges of mountains lying between them. Hence, forests grow on the mountain slopes, and a very active and large lumbering and wood products industry is located here. However, all the lower-lying areas--the valleys, the intermountain basins, and the lower plateaus--receive very little rainfall. Because of silty or sandy soil most of the moisture that does fall on them quickly evaporates and the land is largely treeless.

The northwestern parts of the region are under the influence of Pacific Coast air, and have a winter-spring rainfall maximum, while the southeastern part has a summer maximum and receives much of its rain from violent thunderstorms. Everywhere local conditions of rain and rain shadow are produced by local relief. The main rain-bearing winds west of the Continental Divide blow from the Pacific and bring 80-100 in. of precipitation, including heavy falls of snow to the mountains along the coast. Immediately east of these mountains occurs a change of dramatic suddenness: the rain shadow falls across the adjoining plateaus and basins, and the dense forests of the mountain slopes are separated by only a narrow transition belt from desert-scrub areas where annual precipitation averages 8 to 10 in. Eastward again the surface rises, and the rainfall gradually increases toward the Rockies.

Vegetation: Climate in turn affects vegetation, which tends to vary with both the amount of rainfall and the time and duration of the wetter season. A regular sequence of vegetation zones can be distinguished, both horizontally and vertically; that is, a sequence of zonal changes generally holds good, both at low elevations and high, and between the heart of the desert and the better watered lands surrounding it. The vertical changes move, in general terms, from scrub through grass, woodland and forest. At one end are the lowest-driest areas, desert-shrub vegetation covers the floor of much of the Great Basin. Those parts of the area that are beds of former lakes form salt deserts, on which saltgrass and sage are found. From this vegetational nadir, an increase in rainfall produces a sagebrush-grass combination.

In the southwestern states there is sufficient late summer rain to produce semidesert grasslands, valuable for yearlong grazing. Elsewhere in the intermountain region, however, lack of rain restricts growth of grasses, and the value of range for grazing purposes varies inversely with the amount of sagebrush.

Animal Ecology: The animal ecology follows closely the dominant climate and natural vegetation variations in the region. Since the dominant natural vegetation is grassland and steppe desert, it follows that the fauna are largely herbivorous. In New Mexico the pronghorn antelope ranges into the subtropical grassland; farther west are the Arizona white-tailed and mule deer. Several important carnivores--the coyote, desert fox and puma--live by preying upon them and upon smaller animals.

The grasses of the steppe supply an abundance of seeds, the shrubs and occasional areas of dry forest furnish nesting places, and the mild winter offers a refuge from more rigorous climates. As a result, these lands contain a plentiful bird life: ducks, geese, turkeys, guinea fowl, pheasants, and others.

Smaller subtropical steppe animals include rabbits, marsupial rats, lizards, and snakes. Insect life is at times abundant despite the general aridity. The drier margins of the steppe are the natural breeding grounds of locusts and grasshoppers.

D. Current and Potential Sagebrush Areas

Figure 2 indicates current and potential sagebrush areas in the United States. Much of these areas are characterized by thin soils, restricted moisture, and other extreme environmental conditions. However, large acreages of productive agricultural land in the 11 states also have deteriorated as a result of overgrazing and indiscriminate plowing. The result has been the growth of sagebrush (see Table I) and cheatgrass on much of the land, replacing valuable perennial grasses; the potentially productive aspen has been taken over by timber and brush burns, and many semidesert brush and grass ranges. However, improved farming practices and strict grazing management are restoring large parcels of this land where the more productive kinds of grass exist; where there is good topsoil; and where sagebrush and mesquite, which compete for available moisture with more valuable forage plants, can be economicaly eliminated.

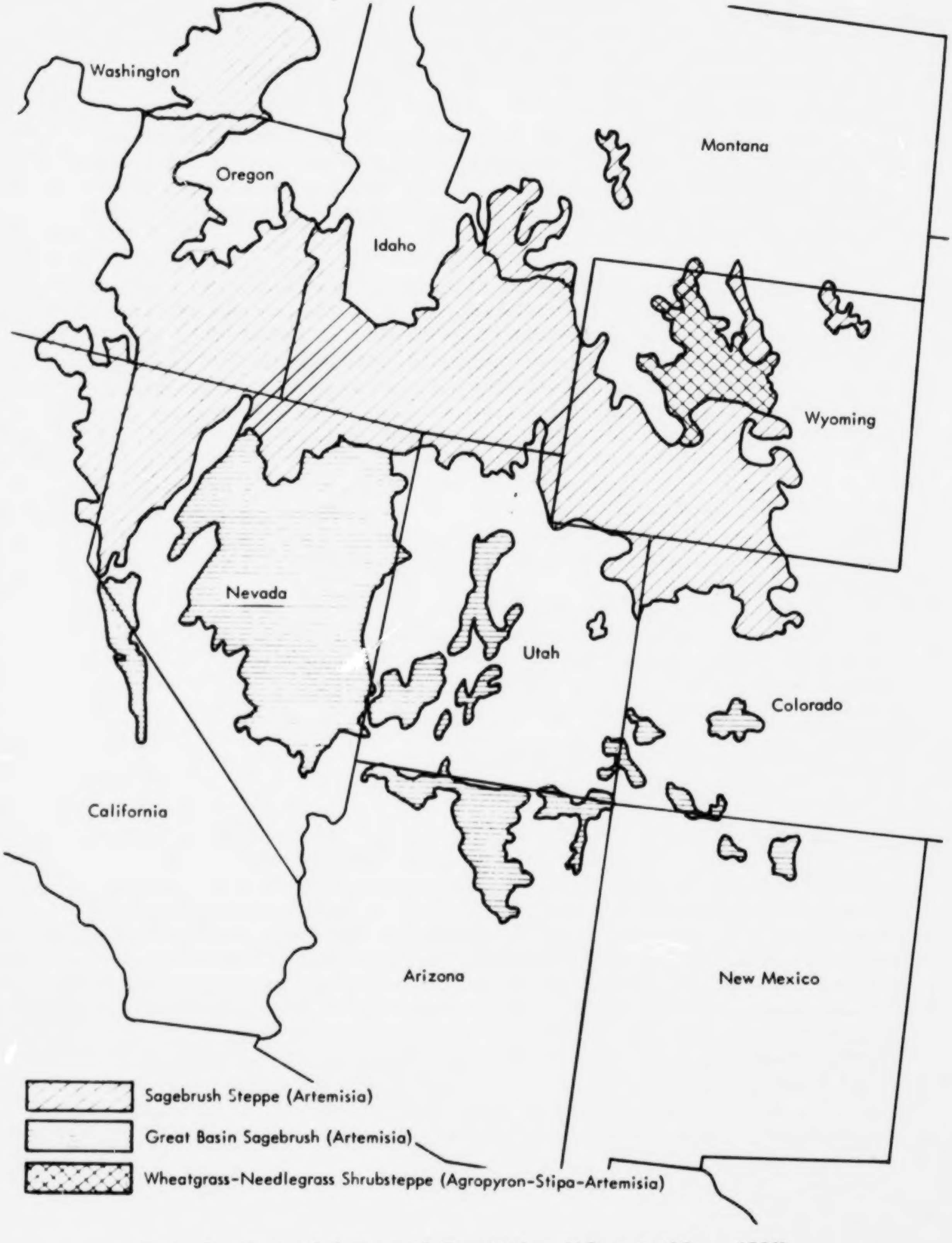
Washington
Oregon
Idaho
Montana
Wyoming
Nevada
Utah
Colorado
California
Arizona
New Mexico
Sagebrush Steppe (Artemisia)
Great Basin Sagebrush (Artemisia)
Wheatgrass-Needlegrass Shrubsteppe (Agropyron-Stipa-Artemisia)

Figure 2 - Potential Natural Vegetation (After Kuchler, 1966)
(Areas of Artemisia Dominance)

TABLE I

CHARACTERISTICS OF SAGEBRUSH (ARTEMISIA) WHERE IT IS THE DOMINANT POTENTIAL NATURAL VEGETATION

Great Basin Sagebrush (Artemisia)

Physiognomy:	Fairly dense to open vegetation of low to medium tall shrubs.
Dominants:	Big sagebrush (*Artemisia tridentata*)
Other Components:	*Agropyron smithii* (northern part), *Artemisia nova*, *Artiplex confertifolia*, and species of *Astragalus*, *Chrysothamnus*, *Coleogyne* (southern part), *Ephedra*, *Eriogonum*, *Lupinus*, *Phacelia*, *Tetradymia*
Occurrence:	Great Basin, eastward to Colorado, southward to Arizona and New Mexico

Sagebrush Steppe (Artemisia-Agropyron)

Physiognomy:	Dense to open grassland with dense to open shrub synusia
Dominants:	Bluebunch wheatgrass (*Agropyron spicatum*), Big sagebrush (*Artemisia tridentata*)
Other Components:	*Artemisia arbuscula* (western part), *A. nova* (eastern part), *Balsamorrhiza sagittata*, *Festuca idahoensis*, *Lithospermum ruderale*, *Lupinus sericeus*, *Oryzopsis hymenoides*, *Phlox spp.*, *Poa nevadensis*, *P. secunda*, *Purshia tridentata*, *Sitanion spp.*
Occurrence:	Pacific Northwest and eastward to Rocky Mountains

Wheatgrass-Needlegrass Shrubsteppe (Agropyron-Stipa-Artemisia)

Physiognomy:	Open grasslands, sometimes fairly dense, with scattered dwarf shrubs
Dominants:	Western wheatgrass (*Agropyron smithii*), Big sagebrush (*Artemisia tridentata*), Plains bluegrass (*Poa arida*), Needle-and-thread grass (*Stipa comata*)
Other Components:	*Agropyron spicatum*, *Artemisia cana*, *A. frigida*, *Artiplex canescens*, *A. confertiofolia*, *Carex filifolia*, *Eurotia lanata*, *Koeleria cristata*, *Sarcobatus vermiculatus*
Occurrence:	Montana, Wyoming

Source: American Geographical Society, Manual to Accompany the Map "Potential Natural Vegetation of the Conterminous United States, A. W. Kuchler, 1964, Special Publication No. 36.

Acreage of Sagebrush, Location and Species: There seem to be differences of opinion as to the acreage of sagebrush in the 11 western states.

The most common estimate of 90 to 96 million acres no doubt comes from the publication by McArdle et al. (1936),[2] but more recent surveys, and publication by Beetle (1960),[1] state that McArdle's estimate is approximately 50 million acres too small for big sagebrush (A. tridentata). Instead of 90 to 96 million acres as originally estimated, we could adjust this figure upward to 144 million acres.

Although there are vast acreages of sagebrush in the 11 western states, commercial pesticide applicators, ranchers, advocates of the sagebrush control program as well as those adverse to the program, realize that a large number of species exist. Some species are specific-site indicators of poor, shallow soils with limited moisture-holding capacities. These areas should not be controlled because results will not lead to increased forage production and costs may be excessive.

The following table (Table II), extracted from Beetle's (1960) bulletin, gives square miles of the respective sagebrush types in the western states.

TABLE II

SQUARE MILES OF SAGEBRUSH IN THE WESTERN UNITED STATES

A. Square Miles of Sagebrush in the 11 Western States Listed Individually by States and by Species (Note: for acreage, multiply by 640)

1.	Wyoming	58,201	1.	*A. tridentata*	226,374
2.	Idaho	58,021	2.	*A. cana*	53,221
3.	Montana	54,211	3.	*A. nova*	43,301
4.	Nevada	53,032	4.	*A. arbuscula*	39,112
5.	Oregon	42,021	5.	*A. bigelovii*	34,010
6.	Utah	41,132	6.	*A. tripartita*	13,002
7.	Colorado	30,203	7.	*A. rigida*	8,010
8.	California	28,221	8.	*A. longiloba*	5,120
9.	Washington	23,011	9.	*A. rothrookii*	103
10.	Arizona	17,112	10.	*A. pygamea*	21
11.	New Mexico	17,110	11.	*A. argilosa*	1

Total square miles - 422,275

B. Square Miles of Sagebrush Types by States (square miles in parentheses)

1. *A. argilosa*: Colorado (1)

2. *A. arbuscula* subsp. *arbuscula*: Oregon (10,000), Idaho, California and Nevada (8,000), Montana and Wyoming (2,000), Washington (1,000), and Utah (10)

3. *A. arguscula* subsp. *thermopola*: Wyoming (100), Idaho and Utah (1)

4. *A. bigelovii*: Arizona and New Mexico (12,000), Utah (8,000), Colorado and Nevada (1,000), and California (10)

5. *A. cana* subsp. *cana*: Montana (20,000), Wyoming (6,000), and Colorado (100)

6. *A. cana* subsp. *bolanderi*: California (6,000), Oregon (4,000), and Nevada (10).

7. *A. cana* subsp. *viscidula*: Wyoming (5,000), Colorado (4,000), Utah (3,000), Nevada (2,000), Montana (100), and New Mexico (10)

8. *A. longiloba*: Wyoming (2,000), Colorado, Idaho and Nevada (1,000), Utah (100), and Montana and Oregon (10)

9. *A. nova*: Nevada (18,000), Utah (10,000), Idaho (6,000), Colorado and Wyoming (4,000), Montana (1,000), Arizona, California and New Mexico (100), and Oregon (1)

10. *A. pygmaea*: Nevada and Utah (10), and Arizona (1)

11. *A. rigida*: Oregon and Washington (4,000), and Idaho (10)

12. *A. rothrookii*: California (100), Colorado (2), and Wyoming (1)

13. *A. tridentata* subsp. *tridentata*: Idaho (25,000), Oregon (22,000), Nevada (20,000), Utah (13,000), Washington (11,000), California (10,000), Colorado (8,000), Arizona and New Mexico (5,000), Wyoming (1,000), and Montana (100)

14. *A. tridentata* subsp. *tridentata* *f.* *parishii*: Arizona, California, Oregon, and Washington (10)

15. *A. tridentata* subsp. *vaseyana*: Wyoming (35,000), Montana (30,000), Colorado (12,000), Idaho (10,000), Utah (7,000), California and Washington (4,000), Nevada (3,000), and Oregon (1,000)

16. *A. tridentata* subsp. *vaseyana* *f.* *spiciformis*: Wyoming and Colorado (100), Idaho and Utah (10), and Montana, Washington, California and Nevada (1)

17. *A. tripartita* subsp. *tripartita*: Idaho (5,000), Washington (3,000), Montana, Idaho and Wyoming (1,000), Utah and Nevada (1)

18. *A. tripartita* subsp. *rupicola*: Wyoming (2,000)

C. Square Miles of Sagebrush in States by Types (square miles in parentheses)

1. Arizona: *A. bigelovii* (12,000), *A. tridentata* subsp. *tridentata* (5,000), *A. nova* (100), *A. tridentata* subsp. *tridentata* *f.* *parishii* (10), *A. cana* subsp. *viscidula* (1), *A. pygamea* (1)

2. California: *A. tridentata* subsp. *tridentata* (10,000), *A. arbuscula* subsp. *arbuscula* (8,000), *A. cana* subsp. *bolanderi* (6,000), *A. tridentata* subsp. *vaseyana* (4,000), *A. rothrookii* and *A. nova* (100), *A. bigelovii* and *A. tridentata* subsp. *tridentata* *f.* *parishii* (10), and *A. tridentata* subsp. *vaseyana* *f.* *spiciformis* (1)

3. Colorado: *A. tridentata* subsp. *vaseyana* (12,000) *A. tridentata* subsp. *tridentata* (8,000), *A. nova* and *A. cana* subsp. *viscidula* (4,000), *A. bigelovii* and *A. longiloba* (1,000), *A. cana* and *A. tridentata* subsp. *vaseyana f. spiciformis* (100), and *A. argilosa* (1)

4. Idaho: *A. tridentata* subsp. *tridentata* (25,000), *A. tridentata* subsp. *vaseyana* (10,000), *A. arbuscula* subsp. *arbuscula* (8,000), *A. nova* (6,000), *A. tripartita* subsp. *tripartita* (5,000), *A. cana* subsp. *viscidula* (3,000), *A. longiloba* (1,000), *A. rigida* and *A. tridentata* subsp. *vaseyana f. spiciformis* (10), *A. arbuscula* subsp. *thermo pola* (1)

5. Montana: *A. tridentata* subsp. *vaseyana* (30,000), *A. cana* subsp. *cana* (20,000), *A. arbuscula* subsp. *arbuscula* (2,000), *A. nova* and *A. tripartita* subsp. *tripartita* (1,000), *A. tridentata* subsp. *tridentata* and *A. cana* subsp. *viscidula* (100), *A. longiloba* (10), and *A. tridentata* subsp. *vaseyana f. spiciformis* (1)

6. Nevada: *A. tridentata* subsp. *tridentata* (20,000), *A. nova* (18,000), *A. arbuscula* subsp. *arbuscula* (8,000), *A. tridentata* subsp. *vaseyana* (3,000), *A. cana* subsp. *viscidula* (2,000), *A. bigelovii* and *A. longiloba* (1,000), *A. cana* subsp. *bolanderi*, *A. pygmaea*, *A. tridentata* subsp. *tridentata f. parishii* (10), and *A. tripartita* subsp. *tripartita* and *A. tridentata* subsp. *vaseyana f. spiciformis* (1)

7. New Mexico: *A. bigelovii* (12,000), *A. tridentata* subsp. *tridentata* (5,000), *A. nova* (100), *A. cana* subsp. *viscidula* (10)

8. Oregon: *A. tridentata* subsp. *tridentata* (22,000), *A. arbuscula* subsp. *arbuscula* (10,000), *A. rigida* (4,000), *A. cana* subsp. *tripartita* (1,000), *A. longiloba* and *A. tridentata* subsp. *tridentata f. parishii* (10), and *A. nova* (1)

9. Utah: *A. tridentata* subsp. *tridentata* (13,000), *A. nova* (10,000), *A. bigelovii* (8,000), *A. tridentata* subsp. *vaseyana* (7,000), *A. cana* subsp. *viscidula* (3,000), *A. longiloba* (100), *A. tridentata* subsp. *tridentata f. spiciformis*, *A. pygmaea*, and *A. arbuscula* subsp. *arbuscula* (10), *A. tripartita* subsp. *tripartita* and *A. arbuscula* subsp. *thermopola* (1)

10. Washington: *A. tridentata* subsp. *tridentata* (11,000), *A. rigida*, *A. tridentata* subsp. *vaseyana* (4,000), *A. tripartita* subsp. *tripartita* (3,000), *A. arbuscula* subsp. *arbuscula* (1,000), *A. tridentata* subsp. *tridentata f. parishii* (10), and *A. tridentata* subsp. *vaseyana f. spiciformis* (1)

11. Wyoming: *A. tridentata* subsp. *vaseyana* (35,000), *A. cana* subsp. *cana* (6,000), *A. cana* subsp. *viscidula* (5,000), *A. nova* (4,000), *A. tripartita* subsp. *rupicola*, *A. longiloba* and *A. arbuscula* (2,000), *A. tridentata* subsp. *tridentata* and *A. tripartita* subsp. *tripartita* (1,000), and *A. tridentata* subsp. *vaseyana f. spiciformis* and *A. arbuscula* subsp. *thermopola* (100)

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III. THE HISTORY OF HERBICIDE USE IN THE STUDY AREA

Prior to 1940, relatively few synthetic organic pesticides were available. Only 14 herbicides were sold in the United States then; eight times that number were sold in 1963.[1]

In previous years, ranchers attempted to control sagebrush mainly by burning.[2] In many instances that method of treatment was of little value, and the sagebrush returned, often thicker than before. Roto beating and other control measures also were tried, but generally these proved to be slow and expensive.

As early as 1946, big sagebrush was shown to be susceptible to treatment with the sodium salt of 2,4-D.[3] Other studies in the 1950's confirmed the feasibility of using 2,4-D for the control of sagebrush.[4,5] Following those initial studies, treatment of sagebrush with herbicides was initiated in several areas. For example, in 1952 the University of Wyoming, with the cooperation of the Big Horn National Forest officials and the Big Horn National Forest Permittees Association, carried out one of the first significant aerial sprayings of sagebrush with chemicals.[2] The results of those trials demonstrated that it was possible to treat sagebrush with herbicide at a reasonable cost with a 200 to 400 percent increase in grass production.

In 1954, approximately 1,000 acres of sagebrush were sprayed in Sublett County, Wyoming, under the auspices of the Agricultural Conservation Program of the Agricultural Stabilization and Conservation Service (ASCS).[6] During the next year an additional 1,100 acres were sprayed in Sublette County and 890 acres were sprayed in Washakie County. Thereafter, the number of acres sprayed steadily increased each year. Table III summarizes the extent of spraying for sagebrush control in Wyoming between 1952 and 1970. Nearly 1,300,000 acres of sagebrush have been sprayed in Wyoming by all government agencies and individuals through 1970. Of that total acreage, about 800,000 acres were sprayed by landowners under ASCS sponsorship, and about 200,000 additional acres were treated by ranchers without ASCS support. Through 1967, approximately 300,000 acres were chemically treated by various other public agencies. Data concerning the number of acres treated for 1968, 1969, and 1970 are incomplete at the present time. However, if we assume that about 50,000 acres of sagebrush were treated each of the three years by public agencies, an estimated total of 1,449,607 acres would have been treated between 1952-1970 in Wyoming.

A typical sagebrush area on the Red Desert of Wyoming is shown in Figure 3. Average production for the area is only 100 lb/acre of air-dry grass. Figure 4 shows the same area after spraying with 2,4-D. Following herbicide treatment, grass production averaged over 300 lb/acre.

TABLE III

ESTIMATED TOTAL ACREAGE OF SAGEBRUSH SPRAYED WITH CHEMICALS IN WYOMING, 1952-1970

	Chemical Control of Sagebrush By:			
	Landowners			
Year	Under ASCS	Not Under ASCS	Agencies	Total
1952		1,050	33	1,083
1953		420	690	1,110
1954	1,000	570	3,473	5,043
1955	1,990	--	1,725	3,715
1956	10,083	3,417	8,186	21,686
1957	3,795	5,105	5,475	14,375
1958	19,533	7,597	21,623	48,753
1959	24,912	7,283	16,351	48,546
1960	16,656	9,437	18,303	44,396
1961	25,246	14,204	12,860	52,310
1962	35,374	22,656	19,868	77,898
1963	38,621	15,379	21,997	75,997
1964	59,712	18,288	25,498	103,498
1965	82,602	17,398	41,742	141,742
1966	83,005	16,995	58,205	158,205
1967	115,923	17,077	40,250	173,250
1968	96,601	14,399	--	111,000
1969	96,573	14,427	--	111,000
1970	92,036	13,964	--	106,000
Totals	803,662	199,666	296,279[a]	1,299,607

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[a] Through 1967.

Sources: Acreage Under ASCS-- Wyoming State ASCS Offices.
Acreage by Public Agencies--Wyoming State Bureau of Land Management and Individual U.S. Forest Service Supervisor's Offices.
1952-62 Data--Kearl, W. G., "A Survey of Big Sagebrush Control in Wyoming, 1952-1964," Wyo. Exp. Sta., M.C. 217 (Nov. 1965).
1963-67 Data--Kearl, W. G., Unpublished Data.

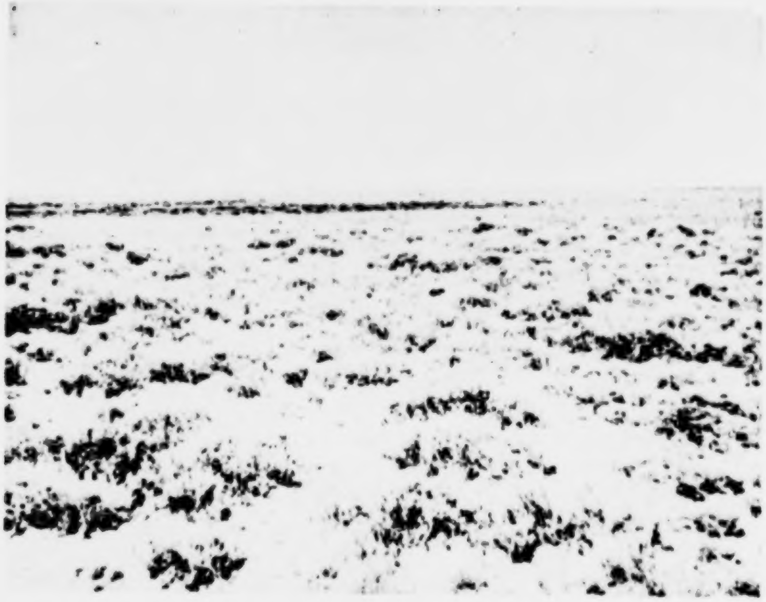

Figure 3 - Typical Big Sagebrush Area on the Red Desert of Wyoming. Sagebrush is small and not very dense. Average annual precipitation is 6-8 in. Area produces only 100 lb/acre air-dry grass.

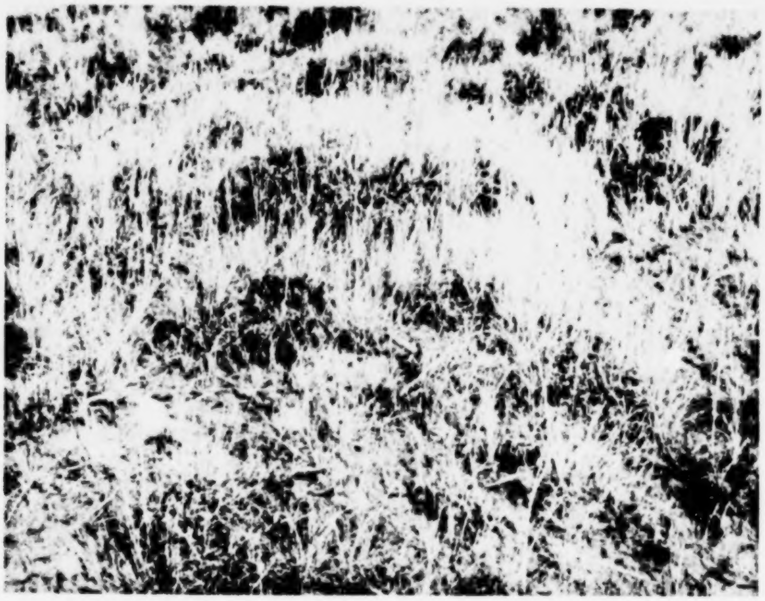

Figure 4 - Same Area as Above, Sprayed with 2 Lb/Acre 2,4-D LVE Ester. Grass production averaged over 300 lb/acre forage after spraying. Moisture is the limiting factor for production.

In Arizona, the records of the Bureau of Land Management (BLM) show that about 30,827 acres of sagebrush have been treated since 1954.[7] Only about 10,577 acres were treated with herbicide, i.e., aerial application of 2,4-D. The remainder was treated by dragging a heavy anchor chain or railing, and by twice-over disc plowing. About 357,000 acres in Arizona are classified as sagebrush type. Most of the pinyon-juniper type has an understory of sagebrush, but is not included in the total sagebrush acreage. The major species of sagebrush in the state include big sagebrush, *Artemisia tridentata*; sand sagebrush, *A. filafalia*; and black sagebrush, *A. nova*. Big sagebrush comprises about 90 percent of the total.

The chemical control of sagebrush in Montana (BLM land) started in 1958.[8] For about 10 years, the chemical control of sagebrush was the major tool emphasized in some areas for watershed site improvement and protection.

Although rest-rotation systems are currently being employed, in some instances sagebrush spraying is still an important tool. Spraying is carried out particularly in areas where it is not practical to wait for comparatively slow results produced by livestock management.

The chemical used in Montana has been 2,4-D with a variety of carriers, including water, diesel oil and invert emulsion. Application rates and pounds of chemical applied per acre have varied according to the carrier used. The following table shows the rates and pounds per acre:

Carrier	Pounds/Acre 2,4-D	Application Rate/Acre
No. 2 Diesel Oil	2	3 gallons
Water	2	5 gallons
Invert Emulsion	1.75	3 gallons

Although BLM personnel in Montana have tried a variety of application and chemical rates, the best results have been obtained with the 3 gal. oil mix. That formulation has been used on a majority of projects, and aircraft were used to apply the herbicide. Table IV shows a breakdown of acres sprayed by calender year.

The first chemical control projects in Oregon were carried out about 1956, utilizing information and results provided largely by the Department of Agriculture Research Station, Squaw Butte, Oregon.[9] Table V gives the number of acres of BLM acreage sprayed per fiscal year.

TABLE IV

ACRES OF SAGEBRUSH LANDS SPRAYED WITH 2,4-D IN MONTANA

Year	Acres Sprayed
1958	1,200
1959	1,957
1960	1,195
1963	6,664
1964	12,343
1965	6,798
1966	11,262
1967	17,361
1968	18,124
1969	8,334
1970	8,501
1971	6,063
Total	95,450

TABLE V

CHEMICAL SAGEBRUSH CONTROL IN OREGON

Fiscal Year	Brush Control (Acres)
Prior to 6/30/63	185,000
1964	46,200
1965	43,800
1966	65,100
1967	40,100
1968	62,600
1969	56,300
1970	37,300
1971	3,500
Total	539,900

In New Mexico, the Bureau of Land Management reported that there have been three chemical sagebrush control projects.[10] All were aerial applications as follows:

1. 1964 - 320 acres - 2 lb of 2,4-D/acre in 5 gal. of water per acre--considered a failure.
2. 1970 - 520 acres - 2 lb of 2,4-D/acre in 5 gal. of water per acre--80 percent kill.
3. 1971 - 560 acres - 2 lb of 2,4-D/acre in 5 gal. of water per acre--kill not counted to date (October, 1971).

Information about total acreages of sagebrush treated on all lands within the state is incomplete.

Artz[11] surveyed range management specialists in Idaho, Nevada, Oregon and Utah, and determined that the following areas of sagebrush have been treated chemically to date (1971):

Sagebrush Area	Acres Treated (2,4-D)
Idaho - Nonfederal	550,000
Nevada	150,000
Oregon	760,000
Utah	240,000
Forest Service - Nevada, Southern Idaho, Utah	300,000
Bureau of Land Mgt. - Idaho, Nevada, Oregon, Utah	1,250,000
Total	2,950,000 Acres

Range specialists in the listed areas estimate that the treated land represents less than 4 percent of the total acreage of sagebrush (approximately 80,000,000 acres).[12] The Forest Service lands in Oregon, which were not included in the estimate of total sagebrush area, might add another 100,000 to 200,000 acres.

The estimated number of acres of sagebrush that have been treated by nonchemical methods are shown in Table VI.

TABLE VI

ACRES OF SAGEBRUSH TREATED BY NONCHEMICAL MEANS (PRIMARILY PLOWED AND DRILLED) IN FOUR WESTERN STATES

States	Acres
Idaho - Nonfederal (very rough est.)	500,000
Nevada- Nonfederal	150,000
Oregon- Nonfederal	110,000
Utah - Nonfederal	120,000
Forest Service - Utah, Nevada and Southern Idaho	150,000
Bureau of Land Mgt. - Idaho, Nevada, Oregon, and Utah	2,500,000
	3,480,000

The number of acres of sagebrush treated chemically, and by annual plowing and seeding are shown in Table VII.

TABLE VII

ACRES OF SAGEBRUSH TREATED WITH 2,4-D AND TREATED BY PLOWING AND SEEDING IN FOUR WESTERN STATES

	Acres Currently Treated Annually	
States	Chemically (2,4-D)	Plowed & Seeded
Idaho - Nonfederal	60,000	11,000
Nevada - Nonfederal	10,000	12,000
Oregon - Nonfederal	105,000	11,000
Utah - Nonfederal	19,000	8,500
Forest Service - Nevada, Southern Oregon, and Utah	30,000	10,000
Bureau of Land Mgt. - Nevada, Idaho, Oregon, and Utah	49,000	113,000
	273,000	165,000

Further insight concerning chemical sagebrush control is available from data furnished by the Agricultural Stabilization and Conservation Service (ASCS) on acres treated to control range shrubs under cost-sharing programs (ASCS Practice B-3). The number of acreas treated by chemical sagebrush control in Idaho, Nevada, Oregon, and Utah are as follows:

State	Average Annual Acreage 1957-61	1963-66	1968-70
Idaho	22,000	43,000	53,000
Nevada	7,000	12,000	13,000
Oregon	20,000	37,000	114,000
Utah	11,000	27,000	16,000
	60,000	119,000	196,000

Remaining Acres Suitable for Treatment: Table VIII shows estimates of the remaining sagebrush acreages believed to be suitable for treatment by the use of current technology.[4]

TABLE VIII

ESTIMATED SAGEBRUSH ACREAGES SUITABLE FOR FURTHER TREATMENT

Area	By Chemicals (2,4-D)	By Other Methods
Idaho - Nonfederal	1,400,000	350,000
Nevada - Nonfederal	2,000,000	1,000,000
Oregon - Nonfederal	5,500,000	1,100,000
Utah - Nonfederal	1,830,000	623,000
Forest Service - Utah, Nevada, and Southern Idaho	438,500	281,500
Bureau of Land Mgt. - Utah, Nevada, Oregon and Idaho[a]	12,500,000	25,000,000
	23,668,000	28,354,500

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[a] Based on recent estimates that about 10 percent of the range improvement job is complete.

These data suggest that roughly another one-fourth to one-third of the total sagebrush acreage, i.e., approximately 23.7 million of 80 million acres, in the four western states shown above could eventually be treated with 2,4-D to further reduce sagebrush density.

Typical of parts of these untreated regions is the big sagebrush infestation common to range areas at the higher elevations (i.e., 8,000 ft) receiving 20 in. annual precipitation. This is shown in Figure 5. Figure 6, on the other hand, is a photograph of the same area after spraying with 2 lb/acre of 2,4-D butyl ester. Air-dry forage production increased to over 1,800 lb/acre within 2 years following treatment.

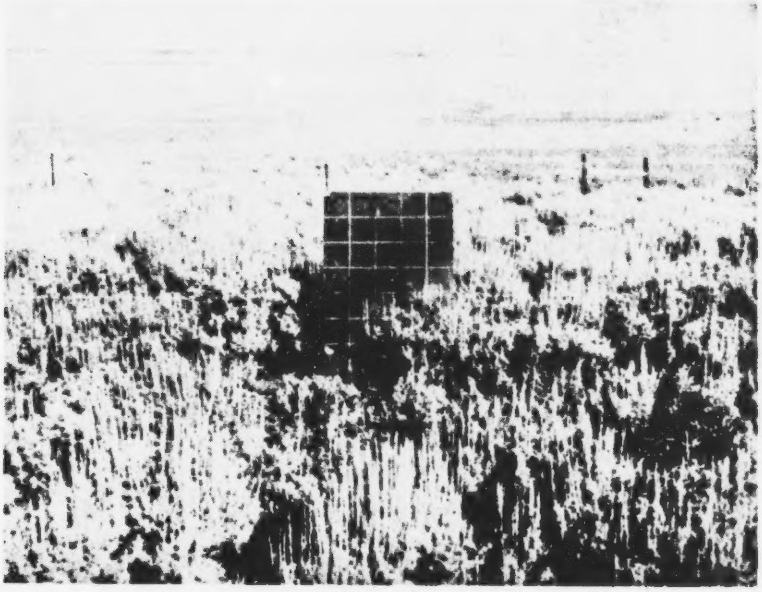

Figure 5 - Typical Big Sagebrush Infestation Common to Range Areas Receiving 20 In. Precipitation per Year at 8,000 Ft Elevation. Air-dry grass production is limited to approximately 500 lb/acre.

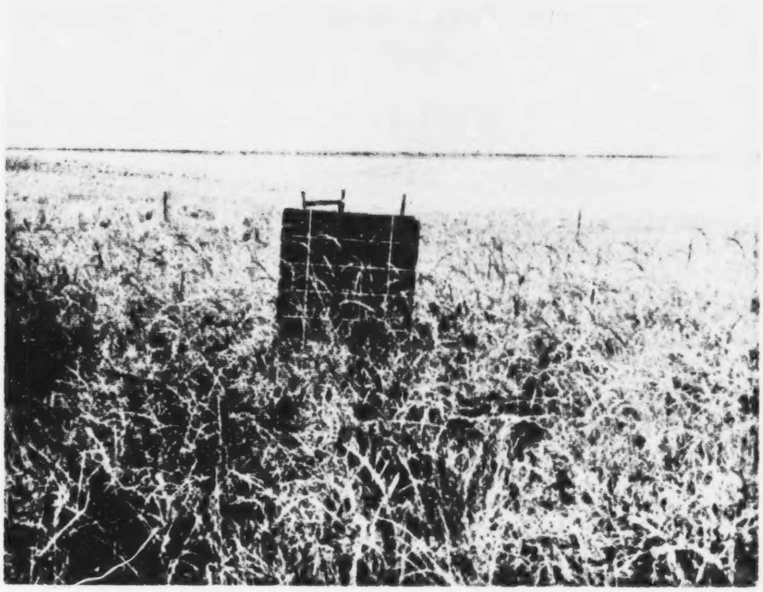

Figure 6 - The Same Area as Above that was Sprayed with 2 Lb/Acre 2,4-D Butyl Ester at a Total Cost of $3.00/Acre. Air-dry forage production increased to over 1,800 lb/acre within 2 years after application.

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IV. INVENTORY AND CURRENT HERBICIDE USE

Based on the number of acres of sagebrush reportedly treated by spraying in 1970, both on government and private lands, slightly less than 400,000 acres were treated. This represents about 0.3 percent of the total big sagebrush acreage. Current estimates of the total acres of sagebrush treated with 2,4-D in the major states within the study area are shown in Table IX.

The usual application rate of 2,4-D for sagebrush control in 1970 was 2 lb of herbicide per acre for a total of approximately 800,000 lb. The U.S. Tariff Commission reported that the total sales of 2,4-D in this country amounted to 43,917,000 lb in 1970.[1] Therefore, it appears that less than 2 percent of the 2,4-D sold was used for sagebrush control.

The only herbicide used for sagebrush control to any significant extent is 2,4-D. Actually, 2,4,5-trichlorophenoxyacetic acid (2,4,5-T) is also an effective chemical control agent, but its cost, like that of another useful phenoxy herbicide, Silvex, is the determining factor in the lack of their use. In 1970, 2,4-D cost $0.30/lb as compared to $0.74/lb for 2,4,5-T, and $1.05/lb for Silvex.[1]

TABLE IX

ESTIMATED TOTAL NUMBER OF ACRES OF SAGEBRUSH TREATED WITH 2,4-D IN THE STUDY AREA DURING 1970

Area Treated		Number of Acres
Idaho, Nevada, Oregon, Utah[a]		273,000
Wyoming[b]		106,000
Montana[c]		8,501
Arizona, New Mexico[d]		1,000
	Total	388,501

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[a] Artz, J. L., Extension Range Specialist, University of Nevada (1971).

[b] Alley, H. P., Professor of Weed Control, University of Wyoming (1971).

[c] Lynd, H. C., Acting State Director, Bureau of Land Management, Billings, Montana (1971).

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V. APPLICATION TECHNIQUES AND HERBICIDE FORMULATIONS USED TO CONTROL SAGEBRUSH

A. 2,4-D Formulations

Virtually all commercial spraying of sagebrush is now conducted with one of the formulations of 2,4-D. The most common formulation employed is the butyl or isopropyl ester of 2,4-D with some use of a low volatile ester near susceptible plants, or when spraying under critical growing conditions.[1] The salts of 2,4-D (amine) are not highly effective on sagebrush and are used only when 30-50 percent control is desired. This practice is common where game animal forage considerations are of major importance.

The selection of 2,4-D as the chemical of choice for treating sagebrush evolved over a period of years of testing, and as a result of experimentation with a variety of herbicides. Not only has 2,4-D proven to be effective against sagebrush, but the material is safe when properly used and its cost is reasonable.[1]

As early as 1946 a limited study conducted in Oregon[2] showed big sagebrush to be susceptible to the sodium salt of 2,4-D. Cornelius and Graham[3] stated that big sagebrush was highly susceptible or hypersensitive to 2,4-D, and showed that a satisfactory kill was obtained by applying 1 lb of the butyl ester of 2,4-D per acre in late June. The higher rates of application gave higher kills, but not enough to warrant the greater expense. One pound per acre applied 30 June gave 85 percent control, and 5 lb/acre applied 30 June gave 100 percent control.

Kissinger, Hull and Vaughn,[4] reporting on experiments conducted at the Beaver Rim area near Lander, Wyoming, found that the isopropyl and amyl esters of 2,4,5-T gave consistently highest kills for a given amount of chemical. For example, 1 lb acid equivalent of 2,4,5-T usually gave somewhat higher kills than 2 lb acid equivalent of 2,4-D, while both 2,4,5-T and mixtures of 2,4,5-T and 2,4-D were more effective than 2,4-D alone. The isopropyl ester formulations killed more big sagebrush than the propylene, glycolbutylether or the butoxyethanol esters. Maleic hydrazide and the dinitro weed killers had little effect on big sagebrush in these experiments. These studies revealed that 75 percent and higher kills of big sagebrush could be obtained with as little as 1 lb of 2,4,5-T ester per acre or 2 lb of the 2,4-D ester per acre.

Hull and Vaughn[5] stated that the type and amount of chemical which killed two-thirds or more of the brush plants varied with the carrier and season. The butyl ester formulation of 2,4-D gave better results than did mixtures of 2,4-D and 2,4,5-T, or the contact sprays. They also found that the higher the concentration of the chemical the better the kill. One pound per acre of the 2,4-D killed, on an average, 63 percent of the sagebrush plants; 1-1/2 lb averaged a 64 percent kill; and 3 lb averaged an 80 percent kill.

Hyder[6] working in Oregon stated that the butyl ester of 2,4-D gave the best results for the money, even though the growth regulator, 2,4,5-T, killed more brush. One and one-half pounds per acre of butyl ester gave 70-80 percent kill. Colorado workers[7] showed that volatile esters of 2,4-D gave more economical control of big sagebrush than the low volatile esters. The herbicide, 2,4,5-T, made a poorer showing as an economical means of control, was less effective than 2,4-D, and more costly. Their tests demonstrated that the best all-around buy in chemicals for control of big sagebrush was the volatile ester of 2,4-D, such as butyl or isopropyl. A 1:1 mix of the isopropyl esters of 2,4-D and 2,4,5-T in an oil emulsion caused an average mortality of 90 percent when applied on May 2, 16, and 24.[2] On the other hand, 2,4-D butyl ester in oil emulsion killed 86 percent, 2,4-D butyl ester in water killed 84 percent, and 2,4-D sodium salt in an oil emulsion killed 35 percent. The difference between 84 percent and the 90 percent is probably not a significant difference, and therefore the two compounds may be considered to have been equal in effectiveness.

Kissinger and Hurd[8] related that, based on sagebrush plants killed per dollar of treatment cost, 1 lb acid equivalent of 2,4,5-T isopropyl and amyl esters, mixed with diesel oil to a total volume of 3 gal/acre, was the most efficient treatment tested. Other promising treatments included 1 lb of 2,4,5-T low volatile propylene glycolbutyletherester per acre and 2 lb/acre of either isopropyl or low volatile esters.

Bohmont,[9] observing the effects of chemicals 75 days after treatment, noted that the low volatile (pentyl) ester of 2,4-D at 2 lb acid per acre caused the most observable toxicity to sagebrush. While 2,4,5-T treatments suppressed seedhead development, the plants partially recovered and seedheads formed during the growing season. With 2,4-D treatment, seedheads were prevented from forming. Bohmont[10] also stated that 1 lb acid per acre of the volatile ester gave 75 percent control 1 year after treatment, and was equal to 1 lb acid/acre of the low volatile ester of 2,4-D. The 2-lb ester treatment was equal to the 2-lb low volatile ester with an average control of 84 percent. Highest control resulting from a single treatment was 3 lb of 2,4-D ester, which killed 96 percent of the sagebrush. The pentyl ester of 2,4,5-T at 1 lb/acre was least effective, giving only 60 percent control.

Bohmont further stated that 2,4-D compounds (both low volatile and volatile) produced the greatest control per dollar invested. For the western region as a whole, 2,4-D ester formulations were recommended for the most economical control. One year's application of the 2,4-D acid at 2 lb/acre could be expected to kill 70-90 percent of the sagebrush, with a second year application of 2 lb 2,4-D acid per acre giving complete kill.

On the basis of extensive work conducted by Alley[11] on the effectiveness of herbicides for sagebrush control, the following conclusions were reached:

(1) While 2,4-D and 2,4,5-T may be used for the control of big sagebrush, 2,4,5-T is neither as effective nor as economical as 2,4-D.

(2) There was no difference in the final sagebrush control resulting from the 2 lb acid per acre treatment of either the volatile or low volatile esters of 2,4-D where growing conditions were not critical.

(3) One application of chemical is economical if 75 percent or more of the brush is killed. Two applications would insure a maximum control, but the cost would be greater.

Early reports on the chemical control of sagebrush varied in their estimates of the effectiveness of the various 2,4-D and 2,4,5-T formulations. None of the western experiment stations, nor the government agencies engaged in the chemical control of sagebrush, recommend 2,4,5-T or the amine formulations of 2,4-D for use in effective control of big sagebrush. All stations in the western United States now recommend either the butyl or isopropyl ester for control purposes. The Wyoming Agricultural Experiment Station does, however, suggest that the low volatile ester of 2,4-D be used in situations of poor moisture and poor growing conditions. Research work and observations of spraying operations have indicated that as high as 20 percent additional control can be obtained with the low volatile ester as compared to the conventional esters under critical growing conditions.

B. Carriers Used

Kissinger, Hull and Vaughn[4] reported that the highest average sagebrush kills were obtained when diesel oil was used as a carrier in chemical treatment. Kissinger and Hurd[8] also reported that diesel oil has generally been a better carrier for all chemicals than water. On the other hand, the USDA Annual Report[12] reported that average kill had been higher when using water than when using oil, except in the case of 2,4-D isopropyl ester. Bohmont[9] stated that there is no apparent difference in the use of carriers in applying the chemical; water or oil is recommended.

However, Hull and Vaughn[5] relate that there was a tendency for oil as a carrier to be more effective than water over longer periods. Alley[13] states that water or oil can be used as a carrier in applying the chemical. Because of the lower volumes of carrier utilized in aerial application and the better coverage and penetration, oil is more popular and more extensively used than water. Two gallons total volume of diesel oil and chemical per acre have given satisfactory coverage and control, whereas more water is required to do the same job.

The grade of oil used should be no lower than No. 2 Grade diesel oil. Use of low grade oil has caused rapid burning of sagebrush foliage, poor translocation of the chemical, and poor control.

Although oil and water are the most common carriers for 2,4-D in spraying operations in recent years, there has been tremendous interest in the use of the invert emulsions, especially by the Department of Interior's Bureau of Land Management. There are probably several reasons why this one organization has used the invert emulsions, even though early research and research conducted by Alley in Wyoming in 1968[14] shows that the use of inverts produces large droplets that are not as effective, and do not give adequate coverage, resulting in poor control of big sagebrush.

In the early 1960's, the Bureau of Land Management changed from the use of oil to the use of water as a carrier for the chemicals. Although no specific reasons were given for the change, indications were that the Bureau believed there was a possibility of getting more chemical into the mountain streams by the use of oil than water. However, Alley has pointed out that oil is a very good penetrant of plants (i.e., sagebrush), and that it is almost impossible to wash off.[14] On the other hand, water will form droplets on a leaf, and rainfall immediately after application can remove herbicide from the leaves and increase the possibility of contaminating underground water or streams within the area.

The Bureau of Land Management has conducted studies with invert materials. In 1966, over 30,000 acres of big sagebrush were sprayed in the desert areas of Wyoming using a bifluid invert system developed by the Stull Chemical Company. As a result of those trials, the Bureau of Land Management is now working on methods to reduce the size of the invert droplets; satisfactory control cannot be obtained on big sagebrush without complete coverage, and this cannot be accomplished with droplets in the neighborhood of 50-100 microns. (The bifluid invert droplets originally were about 500 microns.)[13]

The drift of herbicides, which can damage desirable susceptible crops, is a function of wind and droplet size. Generally, the smaller the droplets the greater the drift. However, it is essential to have a large number of droplets to obtain satisfactory control of wood species like big sagebrush. In 1 gal. of spray per acre, there are only nine 500-micron size droplets per square inch, as compared to 1,164 droplets of 100 microns.[13] These data indicate the need for small droplets to obtain coverage necessary for the control of sagebrush. In the opinion of most weed-control experts, the most effective and efficient way of obtaining satisfactory control of big sagebrush is the use of oil as a carrier.[14] Invert emulsions appear to have their place, but apparently until the liquid is broken up into about 100 microns in size, sagebrush will not be effectively controlled. With this degree of pulverization, inverts will drift as readily as droplets of oil.

C. Time of Application

Date of spraying or stage of plant growth was found to be one of the most important factors for the success of spraying. Hull and Vaughn[5] concluded that when twigs were 1/2 in. long and had approximately one-half of their season's growth, the sagebrush plants were more sensitive than when the twig growth was near completion and the flower stalks had commenced to elongate. Averaging all treatments in which early and late applications might be directly compared, there was an average kill of 66 percent for early spraying and 47 percent kill for late spraying. Treatments made just prior to or during the early bloom stage of native bluegrass gave the highest sagebrush kill.[3] Past work indicates that the maximum susceptibility occurs during the period of most active growth in spring or early summer.

Cornelius and Graham[3] reported that sagebrush in northern California was more susceptible to 2,4-D when about 7 in. or half of the twig growth had been obtained. However, in certain areas twig growth is often less. Extreme variations in annual twig growth have been noted between different sites, between plants, and between years, according to Bohmont.[9] He relates that the activity of 2,4-D and 2,4,5-T is adversely affected by factors which impede normal plant growth. The optimum time to treat a given plant to obtain maximum control is at the most active growth stage, coupled with the lowest ebb of stored food reserves. Data collected throughout the region indicate that big sagebrush should be sprayed when a native blue grass (*Poa secunda* complex) is in full bloom; the common phloxes are in the early seed formation stage of growth; and Idaho fescue (*Festuca idahoensis*) is starting to head, this being the most active growth stage. The sagebrush twigs should have rapid elongation at the time the chemicals are applied for maximum effect.

The Colorado workers indicate that the best time for spraying in the Great Divide area, with its 7,000-ft altitude, is from the last week of May until June 15. For each additional 1,000 ft in elevation, spraying should be delayed 7 to 10 days, and for each 1,000 ft lower elevation, spraying should be 7 to 10 days earlier.

Hull and Vaughn[5] state that sagebrush reacted much the same regardless of age class. There was a tendency for small plants to be either completely dead or completely alive, but the percentage of plants killed was similar for both young and old. Sagebrush plants did not translocate spray materials rapidly. Portions which were missed in spraying remained alive and vigorous, in spite of the fact that other portions of the plant were completely killed. Conclusions drawn from the observations made on the Big Horn experimental plots indicate that the young sagebrush have a tendency to be more tolerant to the selective herbicides than older sagebrush, and that parts of sagebrush clumps completely covered by the chemical spray remained alive.

D. Method of Application

Most spraying of sagebrush in the West is accomplished with the use of fixed-wing aircraft, the majority of which are new-generation aircraft built after 1959 specifically for agricultural aviation application. In some areas, helicopters are used, and it is generally agreed that they get a better penetration and work better in tight areas. The main limitation is the ability to follow the helicopter to the job site with support equipment. Most operators have put in landing strips so that they can continue to use fixed-wing aircraft.

These aircraft are equipped with standard spray assemblies calibrated to deliver the proper amount of material per acre. Usually, 2,4-D is distributed in 2 to 3 gal. of No. 2 diesel oil per acre. Because of the nature of the sagebrush plant, diesel fuel provides better penetration and better coverage (than water, e.g.), and usually 2 gal. of oil are equivalent to using 5 gal. of water per acre. In general, most applications attempt to hold droplet size to 50-100 microns.

Many factors can be used to determine when to apply chemicals. However, experienced operators place more emphasis on the general appearance of the sagebrush, the soil moisture, and temperature. Soil moisture is a limiting factor.

Cook[15] notes that success in sagebrush control has been sporadic on dry foothill sites. Some ranchers have been disappointed by the results, even though they followed recommended practices very carefully. These failures probably come from spraying according to the calendar rather than from close observation of the growing conditions of the plants. To get good results, the sagebrush plants must be in a state of rapid growth.

In Utah--where soil moisture was about 12.5 percent in the upper foot of soil, maximum daytime temperatures were at least 70°, and the temperature at night did not go below 40--control of big sagebrush was good. During extended cold periods the sagebrush plant is inactive; hence, chemicals applied during this period are poorly translocated, and low sagebrush kill results. The clay loam soil in this experimental site area felt moist to the touch. Plants get their moisture more easily from silt loam soil or sandy loam soil than from clay loam soil. Moisture at 10.5 percent in a silt loam soil and 5.5 percent in sandy loam is just as available to plants as 12.5 percent in clay loam soil.

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VI. ABIOTIC FACTORS IN SAGEBRUSH CONTROL

A. Soil Erosion

According to Pechanec et al.,[1] the erosion hazard usually is not increased by spraying sagebrush. Erosion normally is checked by dead standing brush, undisturbed litter cover, and undisturbed soil and grasses. Furthermore, plant cover generally is increased following spraying, thereby reducing the possibility of erosion.

Burning as a method of sagebrush control presents the greatest hazard of erosion.[1] Debris and litter are largely consumed by fire, and the soil is seriously exposed to wind and water erosion. Burning is not recommended on steep slopes or on soils that blow or wash readily.

Because the ground cover is improved as a consequence of sagebrush removal, runoff, and sheet and gully erosion are greatly reduced.

B. Effects on Watershed Areas, Moisture Retention and Snow-Holding Capacities

Upon initiation of commercial sagebrush control programs in the early 1950's, concern was expressed that watersheds (sagebrush lands at the 7,200- to 8,200-ft elevations) might be affected to such an extent that the snow accumulation patterns, moisture reception and depletion, soil erosion, sedimentation, etc., might cause considerable damage to the watershed areas.

Soil-moisture retention and snow-holding capacities, as affected by the chemical control of big sagebrush (Artemisia tridentata Nutt.), were initiated by the Wyoming Agricultural Experiment Station in 1958. Although similar studies have been reported since that time, this study was probably the first such project directly related to chemical control of big sagebrush and its abiotic effects.

The research was conducted by Sonder and Alley[2] in the Big Horn Mountains of north central Wyoming and in the Red Desert of south central Wyoming. In the Big Horn Mountain area elevations reach 8,200 ft and there is an average annual precipitation of 20 in. The original spray trials were applied in 1952 and 1953, the amount of sagebrush control varying from 0 to 100 percent as a result of the various chemical treatments.

The Red Desert area has an elevation of 7,000 ft and an average annual precipitation of 10 in., most of which falls as snow. The plots in this area were treated with butyl ester and the propylene glycol-butyl-ether ester formulations of 2,4-D in June of 1957.

In the Big Horn Experimental trials, three areas with 100 percent control of sagebrush and three untreated areas were selected at random for conducting soil-moisture studies. Four sites were selected at random on the 80-100 percent control and the uncontrolled areas on the Red Desert experimental area. At each of the station locations, in both of the areas, random soil samples of uniform soil type were collected from the surface inch and from depths of 6-7, 12-13, and 18-19 in. The samples were placed in closed metal containers, taken to the laboratory, weighed, oven-dried at 150°C for 24 hr, and the percentage of moisture in the soil was determined.

A second method for determining the relative moisture of the soil was the use of Bouyoucos moisture-absorption blocks. These plaster-of-paris blocks were placed in the soil in July of 1958 at the Bald Ridge study site, and August 1958 in the Red Desert site, at depths of 6, 12, and 18 in., the depths being replicated five times at each of these stations.

Snow surveys were conducted in the Red Desert and Big Horn areas in 1958 and were continued until April 1959. Snow depth and soil moisture measurements were taken along a mapped course across each of the treated and untreated strips. Ten measurements and samples were taken from the treated and untreated areas.

1. Results From the Red Desert Soil-Moisture Studies: Soil-moisture studies made 1 year after initial chemical treatment indicated that areas of 80-100 percent sagebrush control retain more soil moisture than do the untreated areas. The chemically treated areas retained a significantly higher percentage of moisture at the 6-7, 12-13 and 18-19 in. soil depths than did noncontrolled areas. The largest difference in moisture occurred at the depth of 18-19 in. The average difference in total moisture between the controlled and uncontrolled sagebrush areas, regardless of depth, was 1.7 percent, which is significant at the 1 percent level of probability.

Data show that at the 18-19 in. soil depth there was a difference of 3 percent soil moisture between the controlled and uncontrolled sagebrush areas during the summer of 1958; therefore, the controlled area actually contained 63.8 percent more soil moisture than the uncontrolled areas. The greatest moisture difference was observed at the sampling date in July, with an average difference of 3.1 percent at the 6-7 in. depth, 2-4 percent at the 12-13 in. depth, and 4.3 percent at the 18-19 in. level, with a controlled area containing the highest percentage of soil moisture.

The chemically controlled sagebrush plots exhibited a sharp drop in soil moisture from 20 July to 21 August with a slight increase in moisture content from 21 August to 28 September; however, the live sagebrush areas exhibited a steady decline in moisture percentage from July through September.

In June and July 1959, 2 years after treatment, a significantly higher percentage of soil moisture was found at the 12-13 in. and the 18-19 in. depth in the controlled areas than that of the uncontrolled sagebrush area. The controlled area contained 26.6 percent (a difference of 2.4 percentage points) more soil moisture at the 12-13 in. depth and 34.7 percent (a difference of 3.2 percentage points) more water at the 18-19 in. depth than the uncontrolled sagebrush areas on 8 June, with no appreciable difference noted at any depth in July.

2. Big Horn Soil-Moisture Studies: Moisture-retention studies on the Big Horn experimental area 6 years after the initial chemical treatment for control of big sagebrush indicated that a smaller difference in soil moisture existed between the 100 percent chemical controlled and the uncontrolled areas. However, when the factors of dates and depths were disregarded, analysis showed no significant difference between the controlled and uncontrolled areas, even though the 100 percent controlled sagebrush area on the Big Horn site contained 18.2 percent more soil moisture than the untreated area.

Since it requires approximately 3 years for the native grass species to obtain maximum ground cover and production after spraying, it is assumed that the increased grass cover is utilizing moisture released by the dead sagebrush. One should not expect large differences in soil moisture after this lapse of time. Either sagebrush (live) or grass utilizes the available moisture.

3. Big Horn Snow Study: Snow surveys made in April 1958 and May 1959 on the chemically controlled big sagebrush plots in the Big Horn Mountains, an area where very little drifting of snow occurs, indicated that areas of 100 percent control retained snow later in the spring than areas of no control. On 10 April 1958, there was an average snow depth of 23.7 in., containing 6.9 in. of water on the 100 percent chemically controlled areas and only 7.7 in. of snow containing only 2.5 in. of water on the 0 percent controlled areas.

On the uncontrolled areas the ground was frozen and covered with an ice sheet approximately 2 in. in thickness, but on the chemically controlled areas these conditions were absent, and the surface of soil was found to be quite mellow. The soil surface immediately around live sagebrush plants was completely bare. This condition may be caused by the greater canopy of live sagebrush providing more evaporative areas as well as the "black body" radiator effect. The chemically controlled areas were observed to have a very even depth of snow with complete absence of bare areas. The snow measurements made on 2 May 1959, showed that the controlled areas had an average of 9.8 in. of snow, containing 3.4 in. of water, compared with the live sagebrush area which held 8.3 in. of snow containing 2.1 in. of water. One of the uncontrolled plots was completely void of snow, but a 100 percent control plot next to it was still partially covered with snow. Figure 7 is a photograph showing uniform snow cover in a sprayed area, and the absence of snow around sagebrush in an untreated area. Conclusions of the study were:

a. Eighty to 100 percent sagebrush control areas in the Red Desert experimental area, retained a significantly higher percentage of soil moisture 1 year after chemical control than uncontrolled areas.

b. Six years after chemical control, 100 percent controlled areas in the Big Horn Mountains contained a significantly higher percentage of soil moisture in late July than the uncontrolled areas.

c. Sagebrush control had no effect upon the snow-holding capacity in the Red Desert in south central Wyoming, where drifting of snow usually occurs.

d. Controlled sagebrush areas in the Big Horn Mountain region retained snow longer in the spring of the year than did uncontrolled areas.

e. The various width strips, in regions where drifting usually occurs, did not have a measurable effect upon the snow-holding capacity.

As stated in a report by Hutchinson,[3] the eradication of sagebrush on western grazing lands to increase forage from more palatable understory vegetation may also affect water yields from these lands. Many of these grazing lands lie at elevations where the large portion of the annual precipitation occurs as snow. This snow is often redeposited in the lee topographic and vegetative barriers by wind. Where sagebrush is the dominant overstory plant in these vegetative areas, its eradication could affect snow accumulation and change the hydrology of these high elevation grazing lands.

The plots which served as the basis of the snow accumulation and disappearance studies conducted by Hutchinson[3] were only 1/10 of an acre, compared to the 5- to 7.5-acre plots of Sonder and Alley's studies.[2] Although the Hutchinson report does not show the extreme differences reported in the Sonder and Alley study, it does state that the metamorphism and subsequent melt of snow began earlier and proceeded at grater rates in

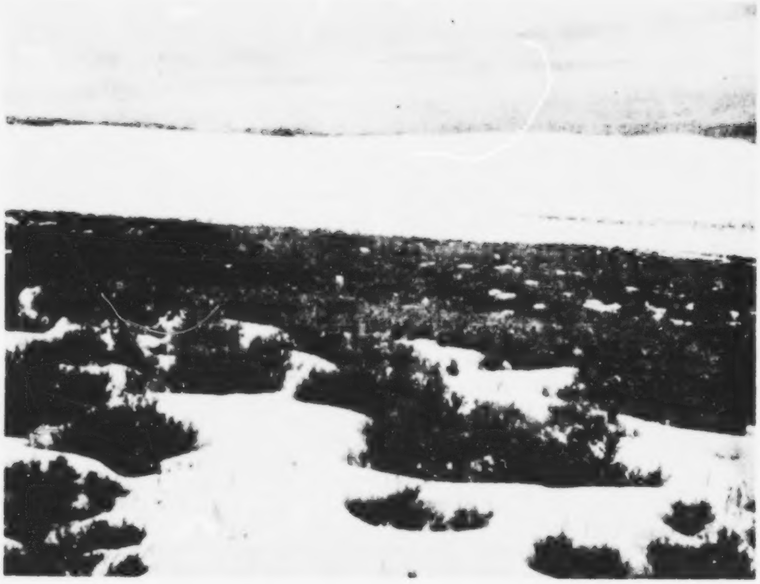

Figure 7 - The Area in the Background is a Sprayed Area With a Uniform Cover of Snow. The area in the foreground is an unsprayed area snowing the absence of snow around the live sagebrush clumps.

and adjacent to sagebrush crowns, a fact reflected in greater water loss from the nonsprayed sagebrush plots during the first month of melt. Little melt occurred in the snow pack over the grassed area (sprayed) during this time, and a gain in water content was measured.

Sonder and Alley[2/] reported that a 2-in. layer of ice covered the soil in the nonsprayed sagebrush areas, evidently a result of interception and alternate melting and freezing of the snow melt. Hutchinson reports just the opposite;[3/] he observed ice sheets only on the grass-covered plots, and since less snow accumulates on grass cover, conversion of sagebrush areas to grass may understandably have profound effects on the hydrology of these high elevation grazing lands. Conclusions of the Hutchinson study were as follows:

a. In areas where induced snow accumulation by topographic configuration is negligible, significantly more snow accumulates in sagebrush-covered areas than in comparable grass-covered areas because of the efficiency of sagebrush crowns in inducing deposition of drifting snow.

b. Continuous layers of ice observed during the considerable portion of the snow-melt period over soil and within the snow pack on the grass-covered areas may change the hydrology of the high-elevation grazing lands when sagebrush is eradicated.

c. The hydrologic importance of the characteristic melt pattern in sagebrush should be further investigated. The trapping of snow and dispersion after spring snowfalls may be important in terms of water yield.

Even though there are some differences in the findings of these two reports, it is only logical to assume that there is more snow accumulated in areas where the sagebrush has been killed than in uncontrolled areas. Sagebrush stands with a 50-60 percent canopy cover intercept large quantities of snow during the winter season. A black-body radiator effect of the live sagebrush clumps causes melting of the snowfall, which in turn reduces the snow cover; much of it is evaporated back into the dry winter air. Robertson[4/] writes that even though sagebrush spreads and disperses a large amount of rain and snow, the competition for soil moisture is believed to be more important.

The amount of evaporation lost is relative to the quantity of precipitation intercepted; it varies with the kind of vegetation and the type and size of storm. Measurements show that interception losses are usually between 5 and 15 percent of the annual rainfall and are fairly constant, under the same vegetative conditions, at various locations.

Ackermanm et al.[5] also stated that sagebrush intercepts and holds snow, increasing the total surface area of the snow. Snow is released from the vegetation by wind or melting. There is often abundant evidence of both. The melting of snow from shrubbery vegetation just before freezing weather may result in the formation of a layer of ice on top of the soil. Forsling[6] states that a layer of ice on the surface of the soil will increase the runoff from the area.

Although the above three reports may be controversial in their results, observations of the sagebrush-covered watersheds and personal consultation with ranchers, who have sprayed watersheds, clearly show that more snow with a higher percentage of moisture accumulates on sagebrush-sprayed areas. In addition, more of the melt goes into the ground and comes out as underground water flow rather than as runoff in the spring. This phenomenon has been noted by ranch operators where watersheds have been sprayed. They report use of springs throughout the growing season. Before the sagebrush was sprayed, the springs dried up early in the year.

Mr. Wes Hyatt, a rancher at Hyattville, Wyoming, and an ardent supporter of chemical control of big sagebrush, stated (personal communication) that "the benefits of moisture conservation on sprayed watersheds may be of greater value than the increased forage production." Before Mr. Hyatt sprayed his watershed, he needed two jeeps, each with a 500-gal. water tank, and two drivers to haul water to his sheep and cattle; since the watershed has been sprayed, a spring has supplied water the entire season. This and other reports of more continuous spring flow clearly show that the water is going into the soil, coming out as clear cool water supplying better trout streams and causing less soil erosion, and reducing the turbidity created by excessive runoff from spring snow melt.

C. Comments on Soil Moisture Retention and Snow-Holding Capacity as Affected by the Chemical Control of Big Sagebrush

Water has long been a key resource in the development of the arid West. The earliest surveys on record searching the potential values of the western United States emphasize the great expanse of arid land in the limited but lush green valleys wherever water occurred. John Wesley Powell's report to the Fifty-First Congress placed on record the importance of watersheds to the maintenance of the great rivers of the U.S. With the ever-increasing population pressure and change in demands for water, there is a growing need to re-evaluate the factors which influence the flow of water in the western United States.

Many conflicting theories have been expounded pertaining to the importance of the sagebrush plant as a means of conserving soil, holding snow and intercepting rainfall. Robertson[7] writes that even though sagebrush spreads and disperses a large amount of rain and snow, the competition for soil moisture is believed to be most important. He further suggests that the normal removal of sagebrush cannot be recommended because of its known benefits in restricting erosion by wind and water and the loss of snow. Renner and Lowe,[8] in surveying the effect of woody species on microclimate, indicate that once a species is established on normal grasslands, it has the effect of increasing the aridity of the area because it provides but little protection against runoff and makes it almost impossible for grasses to become naturally established.

Alley[9] points out that the sagebrush plant affords limited protection to soil erosion. In dense areas of sagebrush which have a canopy cover of 60 percent, there is only 3 percent basal density. In other words, sagebrush plants do not afford protection on the soil surface. The basal area is quite small. When the sagebrush plant is killed, native grass species increase in basal ground cover, affording better soil protection than in uncontrolled areas.

Ackermann and associates,[5] in surveying where our water comes from, indicate that interception losses are usually between 5 and 15 percent of the annual rainfall regardless of the various organic covers. They further suggest that changing the vegetation to reduce the total volume of the brushy canopy would reduce water loss. Studies by Alley and Bohmont[10] in Wyoming show that sagebrush treated by chemical management practices has a definite beneficial effect on snow retention. Increases in stored moisture of 300 percent were obtained in areas on which the sagebrush had been chemically controlled, compared to adjacent lands on which the sagebrush was untreated. Hyder and Sneva[11] concluded that sprayed areas improved moisture relationships by better retention of precipitation, but that the moisture depletion was faster on the chemical-treated areas.

Jones,[12] in working with the transpiration rate of *Artemisia* species, found that an acre of sagebrush on the Red Desert transpired 93,660 gal. of water over a 4-month period, which is equal to 3.44 in. of precipitation. The area receives approximately 8 in. of precipitation annually. In another study, Sheets[13] showed that the maximum evapotranspiration of the untreated plots was 0.10 in/day as compared to 0.06 in/day for the treated sagebrush plots.

Annual precipitation for the Pecos River Basin in New Mexico is approximately 14 in. annually. Only 3-1/2 percent of the total precipitation is drained down the Pecos. More than half of the precipitation is evaporated, and the remainder, taken up through the roots of woody plant species, is transpired through the leaves. Far more water is lost through transpiration than by runoff.[13]

Many of the woody species are not good retardants of soil erosion. Often people do not understand that these species only afford 2-3 percent basal density, whereas grass canopy cover may be as high as 50-60 percent. Native grass species or introduced grass species afford much better protection to soil erosion and percolation of moisture received into the soil.

Chemical sagebrush control has been accepted as a range improvement technique, and many thousands of acres of sagebrush-infested land have been and are being sprayed annually. U.S. Forest Service, Bureau of Land Management, Natural Resources Board, Soil Conservation Service, and many others became concerned with the effect of the control of sagebrush upon the snow-holding and moisture-retention capacity of watershed areas which were being sprayed.

D. General Comments

Most of the sagebrush lands in the West are potentially productive. The increasing land values, shortage of additional rangelands, economic requirements for more efficient production, along with the increasing need for more livestock production, more livestock products and game populations to meet the ever-increasing human population, clearly indicate the need for more production on sagebrush-infested land. The eradication program must be accepted as a range-improvement technique.

Of equal importance may be the manipulation of densely infested watersheds to increase the longevity of water flow from these areas. Water has become one of the most hotly contested items throughout the western drainage area. Any practice which would aid in the increase of water to meet the irrigation or consumptive uses of the expanding population is of utmost importance. Although data may be limited, there is every indication that the manipulation of undesirable vegetation on our vast drainage areas holds great promise for increasing the water flow from these areas.

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VII. EFFECTS OF HERBICIDE USE ON THE BIOTIC FACTORS (FLORA AND FAUNA)

Many conservationists, wildlife biologists, other scientists, and laymen have expressed concern about the possible effects of sagebrush-control programs on the plant and animal life within treatment areas. In some instances such concern has been well justified, and in other situations objections have been based largely on emotional considerations rather than factual data. Game and fish are--as we know--resources close to the people.[1] In the following sections, the effects of 2,4-D herbicide (as used to control sagebrush) on the flora and fauna of the rangelands will be discussed.

A. Direct Effects of 2,4-D on Animals

When properly applied at recommended rates and techniques, 2,4-D is not considered poisonous to man, domestic animals, fish or game.[2] A review of the literature on the toxicity and hazards of 2,4-D is given in Section IX of this report (pp. 109 to 121).

B. The Effect of 2,4-D on Microorganisms

The effects of 2,4-D on microorganisms have been investigated by several workers. After studying 10 species of bacteria and fungi, Lewis and Hammer concluded that 2,4-D applied at normal rates would not seriously affect soil microorganisms.[3] It was suggested that impurities in the herbicide preparation might have some effect on the microorganisms studied.

The United States Department of Agriculture reported that 2,4-D did not accumulate in the soil, and had no adverse effects on soil microorganisms.[2] Conversely, Thornton reported finding 2,4-D residual in the soil,[4] and 2,4-D residues also were found in the soil and killed seedlings 6-9 months after application when the chemical was used as a pre-emergence treatment to kill weeds.[5] The persistence of 2,4-D in soil is dependent upon physical factors like temperature, rainfall, and soil type as well as microflora present.[4,6] Therefore under certain conditions, it could have a more pronounced effect on soil microorganisms than at other times.

A number of organisms in the soil can degrade 2,4-D. They include *Mycoplana sp.*, *Rhizobium melilote*, *Corynebacterium sp.*, *Arthrobacter globiforme*, *Achromobacter sp.*, *Flavobacterium aquatile*, and *Nocardia coeliaca*.[7] The more rapid degradation of 2,4-D observed with repeated treatments is probably because of increased populations of these organisms.

In one study, the persistence of 2,4-D in moist soil was determined by adding 2,4-D to soil in glass jars and placing the jars horizontally at the depths the soil samples were obtained, namely, at the 6, 16, and 36-in. soil depths. Bioassay showed that the 2,4-D was degraded during the first 5 months at all soil depths.[8] Bounds and Colmer[9] incubated a streptomycete (apparently S. viridochromages) with 2,4-D for 7 days. Bioassay of the extract by the cucumber root growth test showed a 42 percent reduction in activity. Glucose-grown cells oxidized 2,4-D after a short lag period.

A soluble enzyme preparation from Arthrobacter grown on 2,4-D metabolized ring-labeled 2,4-D to succinic acid.[10,11] The enzymes catalyzed the conversion of 3,5-dichlorocatechol to 2,4-dichloromuconic acid, which was converted to chloromaleylacetic acid, which in turn was converted to succinic acid. They propose this as the pathway of 2,4-D degradation by microorganisms.

While some microorganisms can metabolize 2,4-D, other microorganisms appear to be inhibited by 2,4-D. Audus[97] reported that three fungi, Gloeosporium olivarum, G. kaki, and Schizophyllum commune, if grown in nutrient media containing 2,4-D or 2,4,5-T, produced an antibiotic metabolite which was active against a range of other fungi at concentrations of 20-200 ppm. This result has not been demonstrated in soil. Arvik, et al.,[12] reported that a 1:4 commercial mixture of picloram and 2,4-D caused no change in composition of algal flora over an 18-month period when applied to soil at a rate of 1.12 to 4.48 kg/ha of 2,4-D. The growth of Cylindrospermum licheniforme was inhibited by 50 ppm of picloram, but not by a picloram-2,4-D mixture at 250 ppm. 2,4-D alone at concentrations below 400 ppm produced no inhibitory affects on C. licheniforme nor on Chlorella vulgaris (Beyer) or Chlorococcum sp. A herbicide concentration of 250 ppm in the top acre 6 in. of soil would be about 500 lb/acre.

Cullimore[13] reported that with the bacteria, Aerobacter aerogenes and Escherichia coli 2,4-D affected the endogenous oxidative activity, which caused a delayed lethal effect. The delayed bactericidal effect of 2,4-D might be affected by cell division and cross wall formation. In the absence of cell division, the cell synthesized protoplasm, but eventually dies.[14]

C. The Response of Sagebrush and Other Shrubs to Treatment With 2,4-D

Spraying of sagebrush with 2,4-D by recommended procedures usually results in a kill of sagebrush ranging from 73 to 92 percent, but kills as low as 33 percent or as high as 100 percent may be obtained.[15] Some of the variability in kill is due to the effect 2,4-D has on various species of sagebrush. For example, a better kill of silver sagebrush (*A. cana*) has been obtained by spraying at a date later than that considered optimum for killing big sagebrush.[16] Of course, the majority of sagebrush control is concerned almost entirely with big sagebrush (*A. tridentata*).

Environmental conditions also influence the amount of kill. As the soil moisture decreases, sagebrush becomes less susceptible to 2,4-D, particularly when the moisture is lost from the top 12 in. of soil.[17,18] It has also been observed that the kill of sagebrush was decreased when the moisture content in the upper 2 ft of soil was less than 12 percent, or when maximum and minimum temperatures were below 70° and 40°F, respectively at the time of application.[19]

Generally, a satisfactory kill can be expected if environmental conditions are favorable for rapid sagebrush growth.[20]

In addition the age of sagebrush influences the mortality rate obtained with 2,4-D treatment. Higher mortality rates were obtained with sagebrush seedlings than in plants 4 years old.[21] Young, mature sagebrush was reported to be more resistant to 2,4-D than old, mature plants.[20]

Small sagebrush plants tend either to be killed or to survive rather than be partially killed. However, the percentage killed was similar for both young and old plants.[22] Hull et al., indicated that sagebrush plants reacted similarly to 2,4-D regardless of age.[23] They based their theory on the fact that since treatment is generally directed toward killing the mature plants which are considered the most resistant group then young plants also should be killed. One explanation might be that seedlings were protected from exposure to herbicide by larger plants.[24] Untreated seedlings could then dominate the area because of reduced competition from older plants. In one study, the number of seedlings on sprayed areas increased as kill of sagebrush increased up to 40-60 percent, and the number of seedlings decreased if higher kills were obtained.[25] Other workers reported fewer young sagebrush plants on areas where there was an initial kill of 75 percent or more, and they estimated that the ranges would remain relatively free of sagebrush seedlings for 4 years.[26] Johnson concluded that where high kill rates were obtained, re-establishment of sagebrush would be slow.[25] It was determined that the average maximum dispersal of sagebrush seedlings from parent plants was 42 ft, with 90 percent within 30 ft.[27]

Partial killing of individual plants is an important factor in appraising the effectiveness of sagebrush spraying. Cook believed that if less than 80 percent of the foliage of a sagebrush plant was killed, the plant would probably regain its original size in a few years;[19] when less than 20 percent of the foliage remained, the plant likely would die in a few years. Therefore, plants with more than 20 percent of their foliage remaining can provide a nucleus for repopulation.

The re-establishment of sagebrush is largely dependent upon the supply of viable seed and the competition from other vegetation.[28] Competition is related to the density and vigor of associated grasses in the area. For example a thin stand of grass with little litter is more favorable for sagebrush establishment than a vigorous stand of grass with a large amount of litter.[29]

The postspraying density and vigor of grasses are influenced by their prespraying density and vigor, growing conditions, and grazing management.

Some workers believe that, finally, the repopulation by sagebrush is dependent upon the climax characteristics of the area. If sagebrush is climax vegetation for a treated area, then it will become re-established. Similarly, if grass is climax, the elimination be over spraying will limit sagebrush density.[30-32,19]

The effects of 2,4-D on other shrubs can be another important factor in evaluating the total effect. Of particular significance is the effect of the herbicide on rabbitbrush which is associated with sage grouse habitat. A greater dosage of 2,4-D is required to kill rabbitbrush than sagebrush.[18] Further, rabbitbrush is more sensitive to 2,4-D later in the year than is sage, and it may never reach a susceptible stage in dry years.[17,18] Rabbitbrush is more difficult to control than sagebrush because it resprouts, is prolific, and efficiently disperses seed.[23,27,34] Therefore, rabbitbrush quickly invades deteriorated ranges.[33] If rabbitbrush is present, it should be expected to increase substantially after sagebrush has been killed in the area.

A limited number of investigations have been made to determine the effects of 2,4-D on other shrubby plants when the chemical was applied for sagebrush control. Generally, only cursory observations have been reported in the literature.[29] It was observed that horsebrush (*Tetradymia convescens*) was sometimes damaged by 2,4-D, but usually it was either unaffected or grew back the following year.[22,23] Some investigators have reported that it appears that *Tetradymia* is benefited by spraying.[34,35]

There is evidence that bitterbrush (Purskia sp.) also benefited from spraying.[35] Conversely, Hyder and Sueva found that bitterbrush (Purshia tridentata) less than 12-in. tall was killed consistently, and that plants over 12-in. tall were not severely damaged if spraying occurred at the time of leaf origin.[36] Survival of bitterbrush was dependent upon a sufficient growing season prior to spraying with 2,4-D.

Serviceberry (Amelonchier alnifolia) was found to be severely damaged by spraying with 2,4-D.[34]

D. Response of Forbs to 2,4-D in Sagebrush Treatment Areas

Only a small number of studies have been made with the sole objective of evaluating the effects of 2,4-D on forbs growing on sagebrush ranges.[29] Observations of the effects on grass as a part of primary studies on sagebrush and grasses have been reported.

Generally, spraying of sagebrush with 2,4-D reduced forbs in the treatment area.[35,37-39]

Blaisdell and Mueggler reported that of 38 forb species studied, damage was nil to 15, light to 10, moderate to 3, and heavy to 10.[34] In other studies on a grassland type, forbs decreased markedly on sites sprayed at an unusually heavy rate of 5.3 lb (acid equivalent) per acre.[38] On the other hand, Alley and Bohmont found decreases in some species were countered by increases in other species resulting in little change in forb density.[40] It also was reported that spraying restricted the growth of weeds during the year of application, but no species were completely eliminated, and weed growth was greater on sprayed sites than on unsprayed areas.[36]

It was noted also that weed density increased in a year of abnormally high precipitation.

A summary of the observations of the effects of 2,4-D on forbs is given in Table X (modified from data by Carr).[29]

Different workers conducted studies under various conditions and no standard methods or descriptions of degree of kill were followed. Therefore, Carr attempted to separate those species most likely to be damaged from those least likely to be damaged by 2,4-D applied according to usual recommendations for sagebrush control.[29]

TABLE X

EFFECTS ON VARIOUS FORBS OF 2,4-D APPLIED FOR SAGEBRUSH CONTROL

Effect	Species	Authorities	References
Beneficial to slight damage	Achillea sp.	Hurd, Bohmont	42,38
	Arenaria sp.	Hurd, Bohmont	42,38
	Cerastium arvense	Hurd, Alley and Bohmont	42,41
	Eriogonum arcuatum	Gierisch	39
	Galium boreale	Hurd	42
	Penstemon radicosus	Blaisdell and Mueggler	35
	Polygonum bistortoides	Hurd	42
	Senecio integerrimus	Blaisdell, Mueggler, and Gierisch	35 39
	Taraxacum officinale	Bohmont, Alley and Bohmont	38,41
Moderate to severe damage	Agoseris glauca	Hurd	42
	Agoseris sp.	Bohmont	38
	Antennaria parvifolia	Gierisch	38
	Antennaria rosea	Hurd	42
	Arnica fulgens	Hurd, Bohmont	42,38
	Astragalus stenophylus	Blaisdell and Mueggler	35
	Aster foliaceus	Hurd	42
	Castilleja lutea	Hurd	49
	Chrysopsis villosa	Gierish	39
Moderate to severe damage	Erigeron caespitosum	Wilbert	43
	Erigeron sp.	Mueggler and Blaisdell	35
	Eriogonum subalpinum	Hurd	42
	Frasera speciosa	Hurd	42
	Lupinus sp.	Mueggler, Blaisdell, Bohmont	38
	L. caudatus	Blaisdell, Mueggler	35

TABLE X (Concluded)

Effect	Species	Authorities	References
	L. leucophylus	Blaisdell and Mueggler	35
	Mertensia oblongifolia	Blaisdell and Mueggler	35
	Myosotis alpestris	Hurd	42
	Orthocarpus leteus	Gierisch	39
	Exytropis sp.	Bohmont	38
	Petradoria pumila	Laycock	24
	Phlox sp.	Bohmont, Hull, et al. Hull and Vaughn	22
	P. hoodii	Wilbert	43
	P. multiflora	Hurd	42
	Potentilla glaucophylla	Hurd	42
	P. hippiana	Gierisch	39
	Zygadenus paniculatus	Hyder and Sneva	18

Species most often reported as moderately to severely damaged were phlox (*Phlox sp.*) and lupine (*Lupinus sp.*).[22,41] However, one worker concluded that *Phlox multiflora* was intermediately affected by 2,4-D, and others noted that damaged *Lupinus* grew again the following year.[23] Gierisch found that umbrella plant (*Eriogonum sp.*) and golden aster (*Chrysopsis villosa*) produced numerous seedlings the year following herbicide spraying.[38]

Mueggler and Blaisdell observed severe damage to fleabone (*Erigeron sp.*) and they indicated that forbs in general might have been damaged more if a better kill of sagebrush had been obtained.[35] It was reported that *Erigeron caespitosum* was severely damaged by an unspecified chemical.[42] Hurd considered aster (*Aster foleaceus*), *Eriogonum subalpinum*, forget-me-not (*Myosotis alpesties*) and *Phlox multiflora* to be intermediate between susceptible and resistant.[41]

Some of the variation observed in the response of forbs to 2,4-D probably was due to the kill criteria used. Giersch believed that changes in the frequency of occurrence did not necessarily indicate comparable changes in basal area or forage production.[38] For example, it was reported that pussytoes (*Antennaria sp.*) on sprayed sites decreased markedly in basal area, but only slightly in frequency.

In summary, 2,4-D at recommended application rates for sagebrush control is toxic to most broadleafed plants. Susceptibility of any species is related to growing conditions, and to the developmental stage of the plants at the time of herbicide application. Annuals are most susceptible when they are young, and perennials are most susceptible from early-bud to early bloom stage.[43]

E. Response of Grasses to 2,4-D

Concentrations of 2,4-D recommended for treating sagebrush should not damage grasses.[44] In fact, grasses appear to be stimulated by 2,4-D.[35] This response may be primarily a result of the effects of 2,4-D on associated shrubs and forbs. Often grass production has increased after spraying. In these cases, sagebrush was sufficiently reduced, and grasses were present prior to treatment.[29] Increased production was a result of increased vigor and spread of original plants rather than the introduction of new plants from seed.[16,23,36]

When sagebrush competition is eliminated, increased water availability usually results in increased grass production. It has been suggested, however, that increased grass production may follow less competition for nitrogen.[36] It also was demonstrated that extracts prepared from sagebrush leaves depressed germination and vigor of several species of grasses including smooth brome (*Bromus inermis*), squirrel-tail (*Sitanion hystrix*) and slender wheatgrass (*Agropyrow trachycaulum*).[45,46]

Some variation in species response have been noted, and these response differences perhaps were because of adaptive variations of the original vegetation. For example, one species might decrease in one area following sagebrush control, and it might increase in another even after herbicide treatment.[29]

Increased grass production is often associated with specific species. Needlegrasses often are increased;[16,36,37] blue grasses were found to increase significantly (presumably *Poa sp.*);[37] other workers found Sandberg bluegrass (*P. nevadensis*) to increase;[16,42] *P. secunda* was observed to increase only slightly in one study area.[38] Other grasses that have been found to increase following sagebrush treatment are grama

(Bouleloua gracilis), bluebrush, wheatgrass (Agropyron spicatum), thickspike wheatgrass (A. dasystachum),[42] wheatgrasses (Agropyron sp.) and fescues (Festuca sp.),[37] Sitanion hystrix,[16] and June grass (Koeleria cristuta).[36] It also was observed that Sitanion hystrix responded best under wet conditions and Koeleria crestata under arid conditions.[36]

Some grasses have decreased after sagebrush control, e.g., Sitanion hystrix,[42] Idaho fescue (Festuca idahoenis)[39] and plains reedgrass (Calamagrostis).[42]

Establishment of grasses has varied considerably from one location to another, depending to a large extent on the vigor of the original grasses and the amount of killed sagebrush. In one study, the production of grasses was increased from 220 lb/acre (air dry) on untreated sites to 460 lb after a 60 percent sagebrush kill, to 540 lb with an 80 percent kill, and to 590 lb with a 95 percent kill.[47] Corneluis and Graham reported that grasses produced over four times more dry weight on sprayed areas than on unsprayed sites.[16] Where a fair understory of grasses existed, grass production increased two- to threefold after a 60-90 percent kill of sagebrush. Figure 8 shows understory of grass and forbs in unsprayed sagebrush area. Figure 9 shows the same area 3 years after spraying with increased grass production.

Grasses respond quickly after sagebrush competition is eliminated. However, two to three growing seasons usually are required before maximum production is reached.[35] Hull et al., concluded that 2 years were needed to obtain a two- to threefold increase in grass production,[23] and the results of another investigation indicated that grass production was greater two to three growing seasons after spraying.[31] However, Hyder and Sueva stated that grass production was greatest in the year of treatment, and decreased after that time.[36]

The maintenance of increased grass production is dependent upon the climax vegetation of the area, and on the grazing practices. When grass is climax vegetation, the developed stands likely will become well-established. Once a vigorous growth of grass is established, the re-establishment of sagebrush will be retarded as well as other species, provided that the grass is not damaged by overgrazing, drought, or other factors.[29]

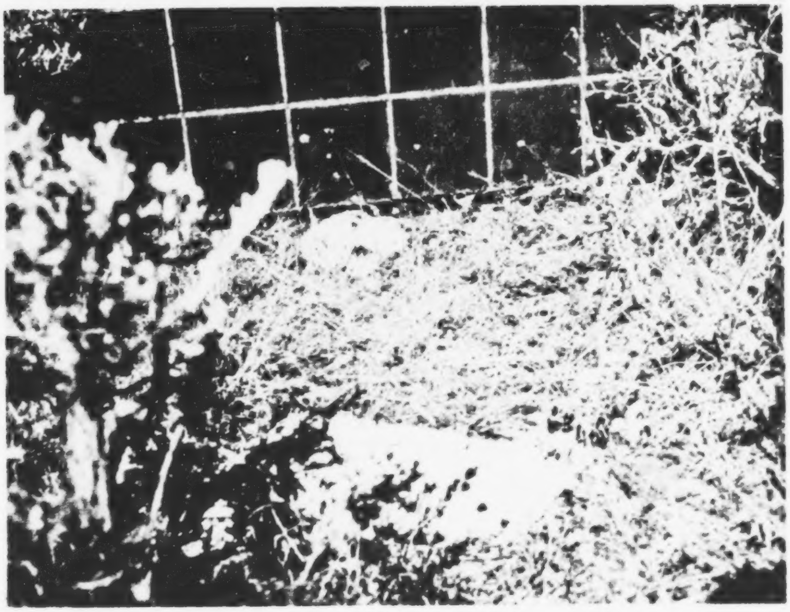

Figure 8 - Understory of Grass and Forbs in Unsprayed Big Sagebrush. Grasses are present but are held back in growth by competition with live sagebrush clumps.

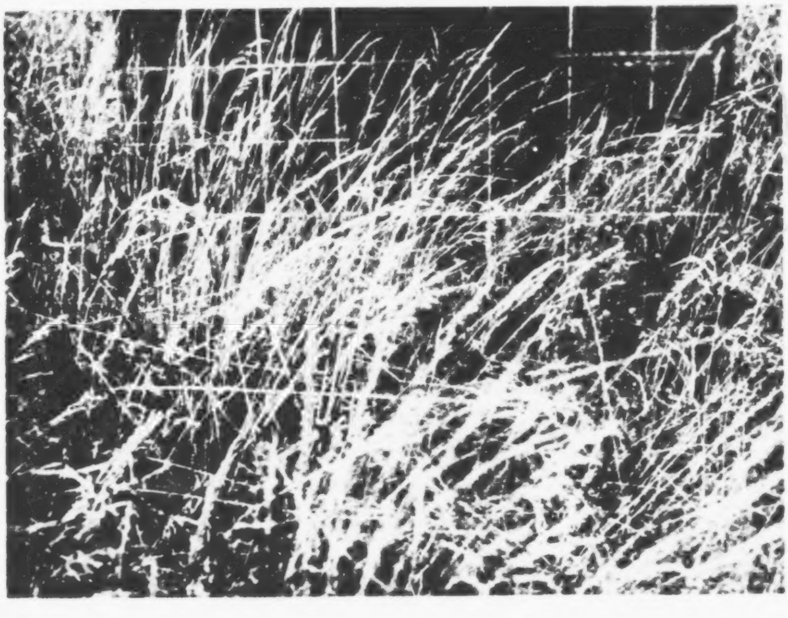

Figure 9 - The Same Area as in the Top Photo 3 Years After Spraying to Kill Big Sagebrush. The increased ground cover stabilizes the soil and increases moisture penetration.

F. Effects of Sagebrush Control on Certain Game Species

The major species of game animals within the sagebrush areas of the rangelands are the pronghorn antelope, mule deer, elk, whitetail deer, moose, bighorn sheep, rabbits, chucker partridge, and sage grouse. Of these species, sage grouse and pronghorn antelope are most closely associated with sagebrush. However, there are other relationships between wildlife and sagebrush of a less spectacular nature.48/ It is well known that species other than antelope and sage grouse utilize sagebrush as food. Certain species also depend upon various forbs for food during some seasons. Some of these forbs are reduced in abundance when they occur with sagebrush within an area treated with 2,4-D.48/ Such a reduction could conceivably have an effect on some species of wildlife. A discussion of the effects of sagebrush control on certain species of wildlife follows.

1. Pronghorn Antelope:

a. Historical background: The exact number of antelope that roamed the continent prior to the entry of white man is unknown, but it has been estimated that there were 30 to 40 million or more.49/ It has been speculated that antelope exceeded the number of bison (*Bison bison*) during the pre-Columbia period. The number of antelope began to decrease during the early nineteenth century, and by the latter part of the century, the population was declining at an alarming rate. Only about 13,000 antelope remained in the entire United States by the second decade of the twentieth century, the lowest population level ever recorded.50/ Table XI shows the estimated number of antelope over a 10-year period. In 1924, Nelson reported slightly over 26,600 antelope in the United States, and the population steadily increased to about 365,000 in 1964.51/ The 1964 population represented an increase of more than 1,000 percent over the original census in 1924.

TABLE XI

ESTIMATED ANTELOPE POPULATION INCREASES AT 10-YEAR INTERVALS FROM 1924 TO 1964 IN THE UNITED STATESb/

Year	Population Estimatea/	Source of Data
1924	26,600	Nelson, 1925b/
1934	131,500b/	U.S. Bureau Sport Fisheries and Wildlife, 1939
1944	246,000	U.S. Bureau Sport Fisheries and Wildlife, 1946
1954	360,000	U.S. Bureau Sport Fisheries and Wildlife, 1956
1964	365,200	Ref. 2

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a/ All figures rounded to closest hundred.

b/ No data available for 1934, consequently, figures for the closest known year (1937) were substituted.

Table XII shows a comparison of estimated antelope population in 1924[49] with 1964 by state.

TABLE XII

A COMPARISON OF ESTIMATED PRONGHORN ANTELOPE NUMBERS IN 1924 (NELSON 1925:3) WITH 1964 FOR THE UNITED STATES[52]

			Difference Between 1924 and 1964	
State	1924[a]	1964	No. of Animals	Percent Increase
1. Arizona	650	10,000	9,350	1,438
2. California	1,060	2,690	1,630	153
3. Colorado	1,230	15,250	14,020	1,140
4. Hawaii	--	130	130	--
5. Idaho	1,480	4,700	3,220	217
6. Kansas	10	140	130	1,300
7. Montana	3,030	95,000	91,970	3,035
8. Nebraska	190	9,000	8,810	4,637
9. Nevada	4,250	4,500	250	6
10. New Mexico	1,680	22,500	20,820	1,239
11. North Dakota	220	14,240	14,020	6,373
12. Oklahoma	20	180	160	800
13. Oregon	2,040	8,950	6,910	339
14. South Dakota	680	27,410	26,730	3,931
15. Texas	2,410	9,380	6,970	289
16. Utah	670	970	300	45
17. Washington	--	120	120	--
18. Wyoming	6,980	140,000	133,020	1,906
Total	26,600	365,160	338,560	1,273

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[a] Original published figures rounded to closest tenth.

The decline in antelope herds from 35,000,000 to less than 20,000 in 75 years was directly related to the movement of the white man across the North American continent.[51] The antelope herds were quickly reduced by relentless year-round shooting of animals for food and pleasure. Man also occupied their preferred habitats, and did not allow the antelope to regain their former abundance.

During the period 1924-1964 the antelope population was reestablished by carrying out several sound conservation and game-management practices. Those measures included: (1) controlled hunting, (2) return of historical range to antelope habitat, and (3) accelerated wildlife management programs.[51] The most significant factor in bringing about an increase in antelope population was the control of man's hunting activities.[52]

b. Habitat: The natural home of the pronghorn antelope was the treeless, grassy and often desert plains of the continent east of the Rocky Mountains. They were abundant on the short-grass plains. In the Great Basin, they inhabited the semidesert bunch-grass and low-sagebrush ranges. In the southwest, antelope occupied the salt desert shrub type, but sometimes wintered among the pinyon-juniper forests. They also frequented the open, grassy, ponderosa pine forests of the mountains, particularly in the park-like openings.[2] Historically, antelope were found in all the western states except Washington, and as far east as Minnesota and Iowa. Their range also extended from Canada to the Gulf Coast. The eastward extent of the antelope's range has retracted to about the 101st meridian.

In Wyoming, where antelope are most abundant, they inhabit a great diversity of vegetation types, but a combination of sagebrush, rabbitbrush and forbs is found on a large portion of their range. On the Red Desert, the aspect is big sagebrush, 6 to 12 in. high. In the Great Basin, several low-growing sagebrush species comprise the vegetation type frequented by antelope. Antelope normally avoid dense stands of tall sagebrush where visibility and mobility are restricted. In New Mexico, antelope range from the short grass and desert shrub up to the mountain grasslands, pinyon-juniper and into the edge of the ponderosa pine--Douglas fir type.[53] In central Montana, the big sagebrush-grassland type on the rolling plains receives the greatest use by antelope, winter and summer.[54] In Texas and Oklahoma, antelope showed definite preference for open grasslands, but travel wooded hillsides and in canyons when necessary.[55]

c. Life history: Prior to the breeding season, bucks gather small harems of up to six or eight doe. Antelope commonly breed as yearlings. As winter approaches, antelope gradually gather into large bands and begin their migratory movements. In the spring, range doe isolate themselves a week or two before the fawns are born in May or June. Twin births commonly occur. Young are able to run with the does in 10 days to 2 weeks, and remain dependent about 2 months. Fawns weigh about 7 lb at birth, while adults weigh 90 to 115 lb. Antelope have a life span of 9 or 10 years.

d. Migration: The daily range of antelope is about 3 square miles, but antelope drift from one range to another without seasonal rhythm.[56] Antelope movements are affected more by storms, forage supplies and availability of water than fixed migration pattern or seasonal movement. Antelope do not thrive when restricted, and transplanting sites should have at least 1 square mile of range for each animal.[57] However, in central Montana, most antelope leave the outlying range areas with the first severe snow storms and winter in rough "breaks." These antelope move from 10 to 23 miles seasonally.[58] At the first heavy snow, antelope of the upper Jackson Hole, Wyoming, migrate 150 miles southward to the Red Desert, but when climate and food supply permit they remain as permanent residents in Jackson Hole.[59]

e. Habitat factors:

(1) Cover: Cover is not a factor for adults except during periods of severe storms, when in some areas, antelope move into breaks and coulees or even woodlands.[57] Antelope typically frequent open, rolling plains. Grasslands, low growing brush-grassland and similar semiarid vegetation types permitting good visibility are commonly preferred. Terrain covered by high, dense sagebrush usually is avoided.[61] The aspect of typical antelope range on Wyoming's Red Desert is big sagebrush, 6 to 12 in. high, while in southeastern Wyoming little sagebrush is present. In the Great Basin, low shrubs 9 to 18 in. high provide the most satisfactory kidding ground.[60] When frightened, antelope follow somewhat well-defined paths which usually course along the natural contours, or draws that are sufficiently open to permit unrestricted movement.

(2) Food: Requirements include quantity and quality considerations. Forage studies on the Red Desert in Wyoming indicate antelope consumed an average of 1.8-1.9 lb of oven dried forage daily.[65] Feeding trials with penned animals averaged 1.5 lb/animal day over an 18-day period.[62]

Antelope prefer plants having the highest protein levels in all seasons. In a Saskatchewan study, grass was dominant in the diet in April, forbs in May and June, deciduous browse in August to October and sagebrush (*Artemisia cana*) and creeping juniper from November to March. Pronghorns were concentrated in the sagebrush-juniper areas in winter.[63] In the Hart Mountain study in Oregon, sagebrush was the dominant food from September through March. Forbs and bitterbrush made up most of the diet in spring and summer, while green grass was taken readily when available during late fall and early spring. Low sagebrush (*Artemisia arbuscula*) was the preferred species of sagebrush.[16] In Montana, the winter diet, by plant utilization, consisted of 93 percent shrubs, 6 percent forbs, and a minor amount of grass. Big sagebrush provided 45 percent of the food in winter. Poor body condition of antelope was probably related to the quality of sagebrush in the diet.[65] A report from Oregon indicates that antelope preferred low sagebrush or nonsagebrush vegetational types and generally they avoided big sagebrush.[66] In a 6-day study in Utah, where antelope were given free choice of 16 browse species in an enclosure, big sagebrush made up about 55 percent of the plants consumed, followed by black sagebrush (A. nova) and juniper which made about 20 percent each. Calculated protein and total digestible nutrient content indicated the nutritional value of the feed was above the maintenance level requirements for livestock.[67] Food preferences at other times of the year were not indicated.

In a 2-year study of vegetation use by antelope and sheep in the Red Desert of Wyoming, forage consumption by antelope, as detected by range analysis methods, was primarily of Douglas rabbitbrush, followed by consumption of big sagebrush.[61] The annual forage production during the 2 years was 147 and 267 lb/acre for big sagebrush, and 89 lb/acre each year for rabbitbrush. The yearly consumption of these species was 13.2 and 9.6 lb/acre of sagebrush and 20.1 and 26.2 lb/acre of rabbitbrush. These two species made up 93 and 97 percent of the total forage consumed in the 2 years. The fall and winter use of sagebrush slightly exceeded the use of rabbitbrush 1 year when heavy snows covered most of the forbs and much of the rabbitbrush. In the second year the use of rabbitbrush was twice as great as for sagebrush, although there was three times as much sagebrush available. Allowable use on shrub species is generally set at 50 percent of yearly production. On this basis, about 60 percent of rabbitbrush was utilized in the year of heaviest use and 10 percent of the sagebrush production was utilized. Severson and May, 1967,[62] report that in a year-long diet study of antelope, as determined by stomach analysis, on Wyoming's Red Desert, big sagebrush comprised from a low of 39.8 percent of the forage consumption in the fall of 1965 to a high of 90.4 percent in the winter of 1964. The same thesis presents data on antelope forage consumption as detected by range analysis methods during the same periods of time as for the stomach analysis study. The range analysis study, reported in pounds of forage consumed per acre, showed a low of 10.8 percent of sagebrush consumed in the summer of 1964 to a high of 50.8 percent in the fall and winter of 1964.

f. Effect of 2,4-D spraying: During an extensive livestock range rehabilitation program carried out in Oregon by the Bureau of Land Management, Reeher of the Oregon State Game Commission reported the results of a 6-year evaluation study.[68] He concluded that the antelope do not use extensive stands of big sagebrush. Investigations also were made to determine if antelope production was different on native ranges as compared to rehabilitated areas. Data obtained by aerial census taken in August 1966, 1967, 1968, and 1969, showed that sage range rehabilitation did not increase the rate of kid production above that on native range.[68] Table XIII shows the results of the aerial counts.

TABLE XIII

ANTELOPE PRODUCTION COUNTS ON TREATED AND NATIVE RANGE, AUGUST 1966-1969

Year	1966		1967		1968		1969	
Range	Treated	Native	Treated	Native	Treated	Native	Treated	Native
Bucks	21	21	36	17	20	36	14	29
Does	75	73	39	59	73	172	73	192
Kids	30	47	13	14	28	88	29	80
Kids/ 100 does	40	64	33	24	40	51	40	42

Other major conclusions made based on the 6-year study were:

(1) Killing of big sagebrush and other woody species by spraying does not make an area attractive to antelope.

(2) Seeding with wheatgrass into sprayed areas does not make the area attractive to antelope.

(3) On spring and summer antelope range, the amount of use on a seeding will be greatest the first few years, then will drop to a lower level.

(4) A plowed and seeded area will receive more antelope use than a sprayed or a sprayed and seeded area.

Results of a survey of ranchers in Wyoming reported that there was no decrease in range use by antelope following spraying of sagebrush.[68] In fact, there were numerous accounts of increased use by antelope in spring and summer, and some reports of increased use by antelope in fall and winter.

2. Mule Deer: The deer of North America are classified as the mule deer and the white-tailed deer. In each classification there are many subspecies which are somewhat limited in range. Mule deer are the prominent species in the study area.

a. Habitat: The mule deer extends from central South Dakota to the Pacific Ocean and from Mexico to central Canada. Apparently, only a lack of feed restricts the location of the deer.[69]

b. Life history: The breeding season for the mule deer is quite variable, depending on location. In Canada, it starts in late October and lasts about 3 weeks. Toward the south, the season starts later and lasts longer. In New Mexico, mating occurs from November to January. The gestation period for mule deer is about 210 days. Fawn drop may occur from early June in northern areas to mid-August in Arizona. Antler drop on the bucks is about 2 months after initiation of the breeding season. As fawning time approaches, the doe separates from the family groups in which they commonly appear, and seeks a place of concealment on the margins of meadows or open glades. Twins are common in mule deer. Fawns weigh about 8 lb at birth and may grow to 475 lb or more, although 200-250 lb is the more common size of a mature buck.

c. Forage and food habits of mule deer: Mule deer consume a great variety of plant species. The palatability of the different species varies with the plant association. A plant may be more highly favored in one association than in another, and seasonally. In spring, grasses make up a high percent of the diet, but drops off in summer as forbs and the new growth of shrubs are consumed in larger amounts. In fall, there is generally an increase in shrubby vegetation and a drop in forbs. Grasses may also increase if autumn rains bring out new growth. In winter herbaceous vegetation may be covered with snow and deciduous shrubs have no leaves, so only the taller browse plants are available. The more important shrubs and trees used in winter include bitterbrush, mountain-mahogany, sagebrush, serviceberry, junipers, cherries, ceanothus, oaks, aspen and cliffrose.

Deer do well in the prairie and short grass plains region where shrubs and hardwoods are a component of the grassland.

Winter range is the limiting factor of deer populations over much of their habitat.[70]

Sagebrush has long been considered an important component of the winter feed for mule deer. Smith[71] attempted to determine the value of sagebrush as a winter food since the chemical analysis of big sagebrush showed it to be half as high in digestible protein and twice as high in digestible fats and carbohydrates as green alfalfa. The digestible nutrient content is well above the minimum for domestic ruminants. Of four doe and two bucks fed a choice of big sagebrush (*Artemesia tridentata*) and black sagebrush (*A. nova*), one doe refused to eat, one died, two doe ate so little they were removed from the test and put on more desirable feed, and the two bucks lost 6-1/2 and 9 lb in a 21-day and 31-day period, respectively, while consuming 2.1 to 2.8 lb of sagebrush daily. Black sage was preferred over big sagebrush.

In another feeding test with captive deer, Smith et al.,[72] gave deer a choice of 15 species of browse. Sagebrush was grazed for the shortest time of all species in 1 year and ranked 12th in amount consumed. In a second test, sagebrush ranked fifth in time grazed and sixth in amount consumed out of six browse species.

In a third test, Smith[73] fed mule deer on diets of sagebrush, juniper, oak and combinations of the three species during three winters. Doe were weighed weekly as a guide for judging the duration of the test. The shortest mean duration was recorded with sagebrush. The greatest average weight loss was observed in deer on sagebrush only. The average daily consumption was as follows:

Sagebrush	0.43 lb
Juniper	0.78
Oak	2.25
Sagebrush plus juniper	1.23
Sagebrush plus oak	2.20
Juniper plus oak	1.44
Juniper, oak and sagebrush	2.73

Sagebrush is highly nutritious, but low in palatability for deer. The data on the above tests suggest that deer have a limit on their consumption of sagebrush which is little affected by other forage available.

Smith and Julander[74] studied the similarity of diet in sheep and deer. In spring and summer both animals ate large quantities of the same species. Deer wintered on the sheep autumn range, and the sheep were moved to new range. Sagebrush made up 64 percent of the deer's diet as compared to 3 percent for sheep. Bitterbrush, oak, and mountain mahogany were over utilized on the deer winter range.

In Montana, Wilkins[75] collected rumen samples to determine the diet of deer. In the summer, summer forbs made up about 75 percent of the samples and browse about 20 percent. Bitterbrush and huckleberry were the most important browse species. In the fall months, browse made up about 75 percent of the diet with bitterbrush and snowberry the most important of nine species. Sagebrush first occurred in the samples in mid-October. In winter, browse was again the dominant type food with big sagebrush ranking first and making up 25 percent of the diet. The amount of bitterbrush dropped off sharply. The decline in bitterbrush use and increase in sagebrush might be attributed to the decreased availability of bitterbrush. When the use of bitterbrush declined, the plants appeared to be over utilized.

The apparent preference by deer for browse species other than sagebrush is possibly a result of the effect of the essential oils of sagebrush on the rumen microbial activity. These oils inhibit the action of gram-positive and gram-negative bacteria and also the growth of deer rumen microorganisms.[76] In artificial rumen studies, the rate of cellulose digestion was decreased by the addition of 0.002 ml of oil and inhibited by 0.04 ml. The addition of 0.1 ml of oils to deer rumen contents decreased the rate of gas production and the volatile fatty acid concentration. The appetite and rumen movement of a fistulated steer ceased completely after three 7 lb/day portions of sagebrush were added.

Olfaction is the primary sense used by deer in selecting food. Certain volatile substance in plants which contribute to their aroma inhibit the growth of rumen bacteria. Deer tolerate small amounts of unpalatable plants. Good correlation has been found between unpalatability and the inhibitory effect of essential oils.[77] Powell[78] found that the volatile oil content in big sagebrush leaves varied greatly on different sites, ranging from 3.5 percent of air dry weight in short plants to 6.0 percent in tall plants on favorable sites. Oil content was highly correlated with sagebrush size and the amount of magnesium and phosphorus in the A horizon. He suggests that tall big sagebrush plants on favorable growth sites should be replaced with more palatable species.

Plummer, et al.,[79] suggests treatment of areas covered with dense brush to improve big game range. A good balance of browse and herbaceous plants is desirable. Even with ample browse, an area may not have enough grass and forbs to provide succulent forage in the critical periods of late winter and early spring.

Bitterbrush digestibility appears to be less in November and December (the period of greatest use) than in March. Big sagebrush was extremely unpalatable. Bitterbrush appeared to be extremely palatable and would maintain deer for several weeks with only a slight loss of weight. When the decrease in bitterbrush was noted, the use was excessive.[80]

Studies in Montana have indicated that mule deer use a high amount of forbs in summer, including the following investigations: Lovaas;[81] Little Belt Mountain; South;[82] Scudder Creek Area, Beaverhead County; Mackie;[82] Missouri River Breaks and Morris and Schwartz;[83] and National Bison Range. All the studies reported the utilization of one or more species of Artemisia and Mackie[14] reported Artemisia tridentata as the most important taxon in the diet of mule deer for both winter and spring.

Figure 10 shows the average contents found in the stomachs of 101 mule deer. The studies were carried out in Colorado during the winter period, 1964-65, by Keiss.[84] Grass accounted for about 28 percent of the stomach contents, and sagebrush (Artemisia) approximately 8 percent. The results of the study indicated that grass was the major winter food of the mule deer, and that sagebrush also was important as a food item.

Figure 11 also supports those indications and shows the frequency of occurrence of various materials in 101 mule deer stomachs. Twig fragments were found about 73 percent of the time, grass 74 percent, deer hair 65 percent, and sagebrush approximately 52 percent.[84]

d. Effect of 2,4-D spraying: Studies made by Anderson in Colorado demonstrated that mule deer used oak-dominated habitats significantly more than three sagebrush-and coniferous-dominated habitats both before and following spraying with 2,4-D.[85] Conversely, cattle were observed to utilize the sprayed areas more than the oak- and conifer-dominated areas both prior to and after herbicide treatment.

Reeher conducted a study over a 6-year period in which he estimated the land use by deer in areas before and after 2,4-D spraying.[86] Spraying was carried out in May 1965 at the Horse Flat area in southeastern Oregon. From 1965 through 1967 the deer use of the treated land was greater than of the control site. In 1968, the use of the control area was slightly more than the sprayed area.

3. Whitetail Deer: The whitetail deer, one of the two species of deer found in North America, is within the study area. However, the mule deer is the most prominent species in the sagebrush areas.

a. Habitat: Generally, the whitetail deer is found primarily east of the Rocky Mountains. However, there are several subspecies of whitetail deer in the northern and southern states of the western United States.[69]

b. Forage and food habits of the whitetail deer: The food habits of the whitetail deer on Missouri River bottomlands in northcentral Montana were studied by Allen.[19] He found that rumen collected from 10 deer in summer contained about 54 percent forbs. Studies of feeding sites showed a 95 percent utilization of forbs (percent of all plant usage). Major native forbs used included hemp dogbone (Apoeynum cannabinum), kochia (Kochia scoparia), and bushy knotweed (Polygonum vamosissium). Browse comprised 81 percent of the contents of 13 fall rumen samples, and forbs made up 17 percent.

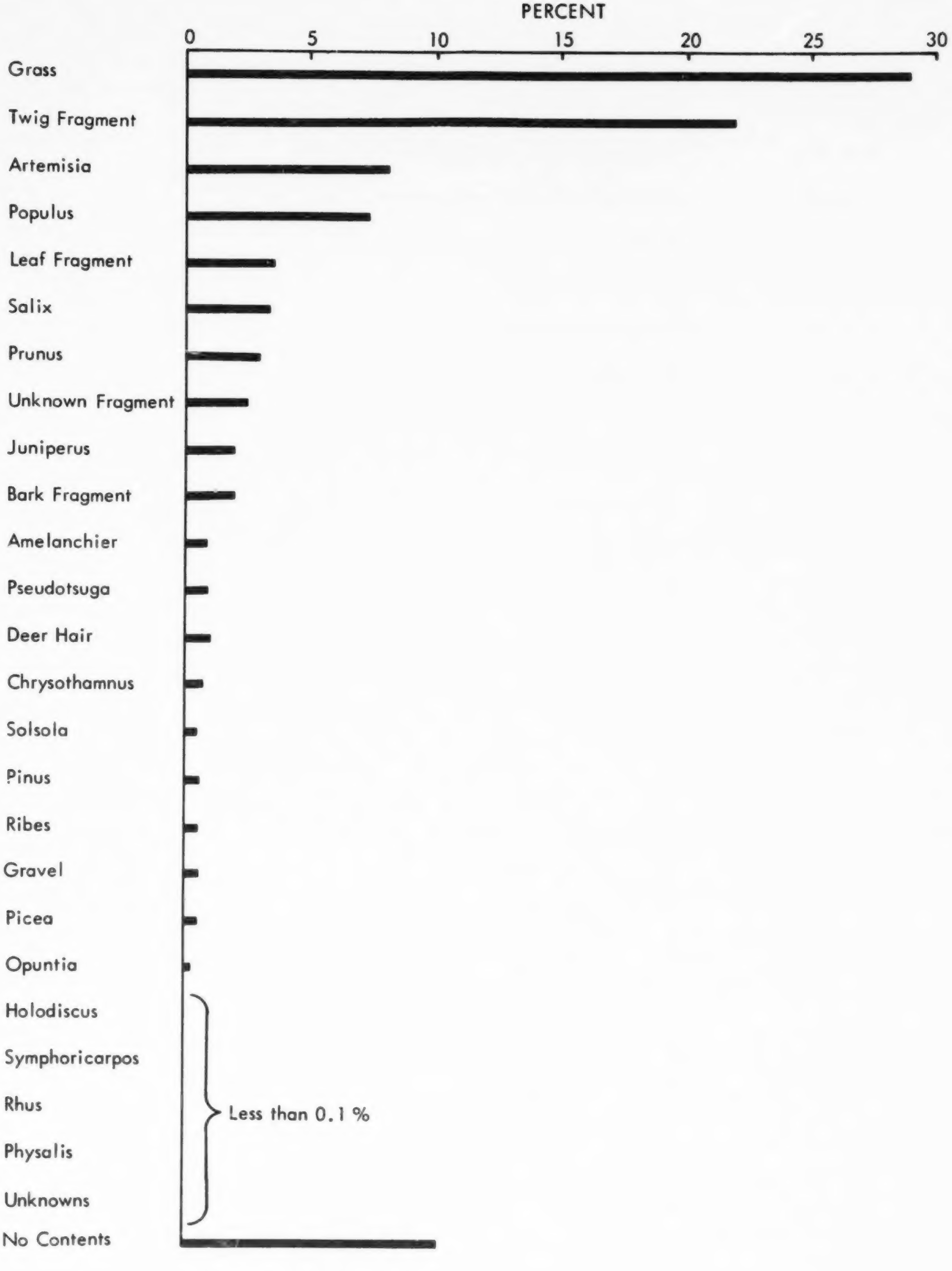

Figure 10 - Average Contents Found in Each of 101 Mule Deer Stomachs

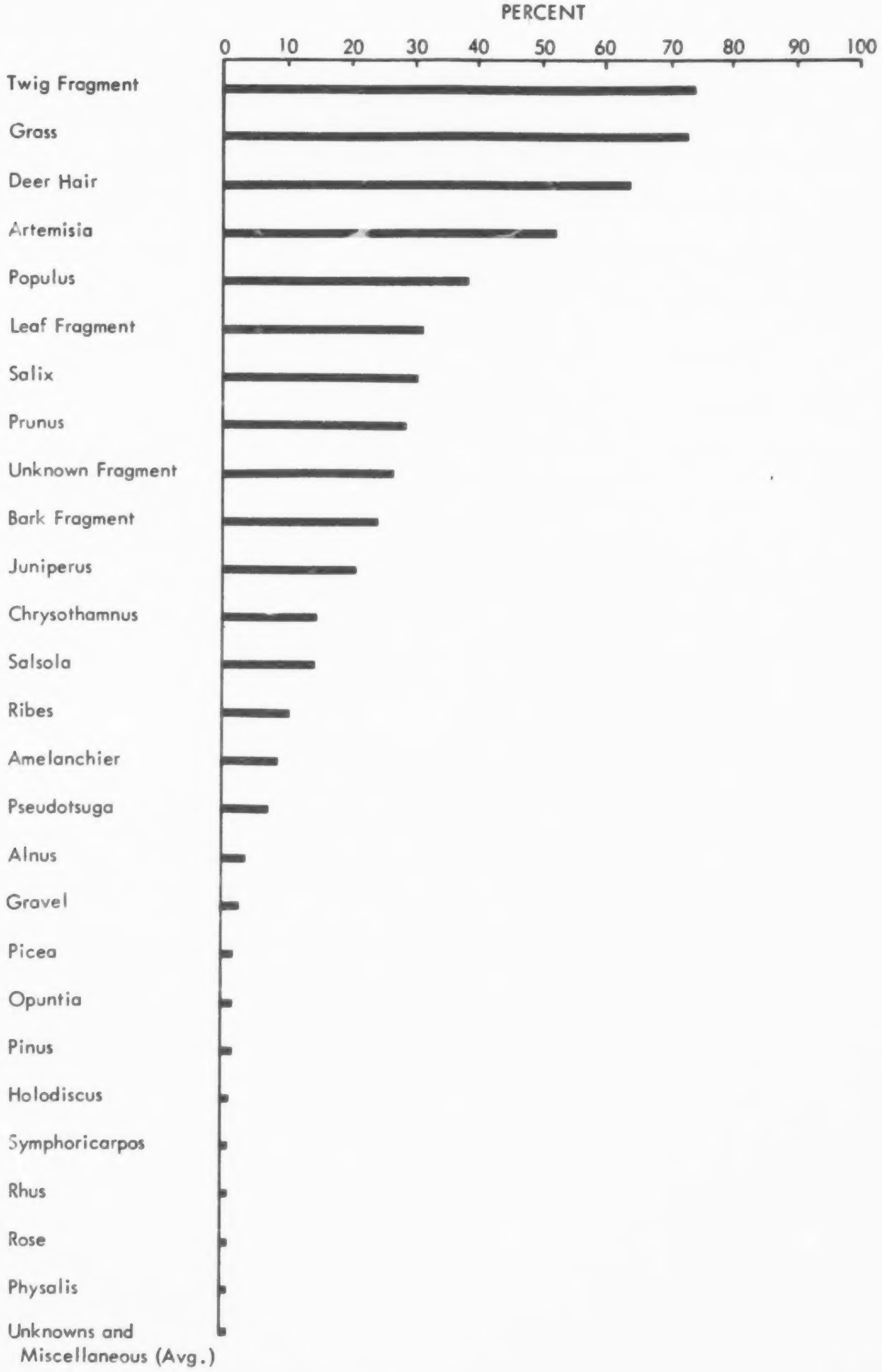

Figure 11 - Frequency of Occurrence in 101 Mule Deer Stomachs

Examination of rumens during the winter revealed that browse was the most significant component, accounting for 65 percent of the contents. Longleaf sagebrush (Antemisia longifolia) was a significant item, or 12 percent of the rumen. Four deer collected from "breaks" had utilized the most sagebrush (Artemisia sp.).

Thirteen rumens examined during the spring revealed percentages of 43, 18, and 38, respectively for browse, forbs, and grass. Grass apparently was a significant food item only during spring, and only for a short period which coincided with the initial "green up."

A total of 25 winter feeding sites of whitetail deer in the Sun River area (Montana) were studied by Schallenberger.88/ He reported that the percentages of use for grass and grass-like plants, forbs, and browse were 5, 30, and 65, respectively. Fringed sagewort (Artemisia frigida) rated seventh among the browse plants used by the deer.

c. Effect of 2,4-D spraying: The effects of 2,4-D application for sagebrush control would be expected to be about the same for the whitetail deer as for the mule deer (see p. 71). A drastic reduction of certain forbs on summer ranges possibly could have the most serious detrimental effect on the whitetail deer.

4. Sage Grouse (Centrocerus urophasianus):

a. Habitat: The original range of the sage grouse closely conformed to the distribution of the big sagebrush, Artemisia tridentata Nutt, and related species. The area included the semiarid plains of the intermountain and northwestern states and the southern border of the three southwestern Canadian provinces. It originally extended from western Kansas, western Nebraska and the western Dakotas westward to include northeastern Arizona, northwestern New Mexico, the northwestern section of Colorado and practically all of Montana, Idaho, Wyoming, Nevada, and Utah; excluding the forested mountainous regions. It extended into the east central portion of California, the eastern halves of Oregon and Washington and the southern border of three provinces of Canada. Within this extensive area the sagebrush grass and salt desert shrub type ranges furnished the habitat requirements of the sage grouse. The sagebrush grass range varies in elevation from 2,000 to 8,000 ft, with a precipitation varying from 5 to 30 in. The precipitation of the salt desert shrub ranges vary from 5 to 10 in. yearly. Sage grouse are most commonly encountered near the mountains. High plateaus and intermountain valleys provide the best conditions for the survival of sage grouse populations.89/

More than 50 percent of the original sage grouse habitat has been eliminated, yet the geographical distribution of the species has remained relatively unchanged. A reduction in sage grouse numbers has accompanied the change in habitat.[89] The principal habitat areas presently include the Great Basin, Wyoming, and eastern Montana.

b. Life history: Male sage grouse may engage in strutting activities in late January or early February on their daily roosting areas. Usually in March they move to their strutting grounds. The time of maximum appearance on the strutting grounds will vary with location and the weather conditions. In Wyoming the peak appearance is from about April 10 to May 20. Hens may appear on the strutting grounds in mid-March, but the peak of mating is usually after mid-April.[89]

The size of strutting ground varies from a few hundred square feet to several acres, depending on the number of males utilizing the grounds.[89,90] A strutting ground may support a few to several hundred birds. The grounds appear to be located at random. The same strutting grounds are used year after year. Usually the grounds are rather bare of brush, and frequently areas cleared by bulldozers or fire are used as a strutting area. The nesting areas are usually in the vicinity of the strutting ground, but a hen may travel as far as 15-20 miles after mating before nesting.[91]

Hens start laying in 7-14 days after mating, and take about 10 days to lay a clutch which may contain from a few eggs to as many as 13. The incubation period is 21-22 days. Within a few hours after hatching, the chicks are ready to leave the nest, and are able to fly within 2 weeks. By 8 weeks the young birds have essentially acquired their full plummage and look like the hen. The young chicks attain a state of independence from the hen at about 10 to 12 weeks of age, and reach maturity at about 6 months.[89]

Sage grouse are inclined to be gregarious at all seasons of the year and even nest in close proximity. The mature birds possess well developed senses of orientation and homing, and have returned to their original grounds after being planted 100 miles or more distant.[89]

With the onset of fall, the sage grouse retreats to the sagebrush grass range type. The daytime resting areas are in the taller brush in draws and gullies and along stream beds. At night the birds merely squat within openings or at the bases of individual bushes. During the fall and winter a single roosting area may encompass several dozen acres and involve several hundred birds.[89]

Migration of sage grouse is dependent on locality. In some areas there is little migration; in others, they require relatively large areas to complete their annual cycle. Wintering usually occurs in areas of low snow depths. In summer the birds move upward in elevation, or on to meadow areas. Food plants develop along an elevational gradient and sage grouse, especially the broods, move along the same gradient as the vegetation at the lower elevations becomes dessicated.[92-94] The distance traveled in a normal cycle may exceed 50 miles. In agricultural areas sage grouse commonly summer in the vicinity of alfalfa fields or other crops.

c. Survival factors:

(1) Food: The juvenile sage grouse's diet consists predominately of insects and forbs. During the first week after hatching, insects make up the greater part of the diet.[95] Peterson[96] reported that insects made up 60 percent of the diet during this period, while Patterson[89] reported insects make up 77 percent. As the birds grew older they consumed less insects and a progressively greater percentage of forbs. Peterson[96] found that insects made up about 5 percent of the diet at 12 weeks and forbs averaged 75 percent of the diet through this period. The preferred forbs were dandelion and salsify. Sagebrush received little use until the birds were 11 weeks old, but the amount gradually increased during the summer thereafter. Patterson[89] reported that sagebrush made up about 45 percent of the adult bird's diet in the summer, 81 percent in the fall, 99.7 percent in winter and 86 percent in spring. The average percent sagebrush from all stomach content analyses for a year was 77 percent.

Stomach analysis of sage grouse killed in early September in California showed that sagebrush made up 64 percent of the volume in 2 years, but only 29 percent in a third year.[94] Clover leaves and rush leafage were important components the first 2 years, while prickly lettuce flowers and grasshoppers made up 21 and 22 percent, respectively, of the volume in the third year.

Savage[94] found that sagebrush made up 56 percent of stomach contents of adult cocks in the summer, the remainder being predominantly forbs. Dalke, et al.,[93] reported that black sagebrush (A. nova) was preferred over big sagebrush (A. tridentata) as a winter feed. Barber[98] found that penned sage grouse fed almost exclusively on small sagebrush, i.e., plants less than 5 in. tall. An analysis of big sagebrush leaves showed that the leaves of small plants were lower in ether extract and essential oils than were the leaves of the taller plants.[99] The tall big sagebrush plants grew on the more favorable sites that tend to have a higher content of magnesium and phosphorus in the A horizon. There is uncertainty as to the importance of the content of essential oils in the since sage grouse appear to excrete these oils in the feces in quantities roughly equal to amounts ingested.[98]

Broods occupy sites with fewer shrubs than do the adult grouse as forbs are more abundant where the brush is less dense. As the vegetation at the lower elevations dries up, the broods move upward or on to meadow areas with a good water supply.[94] The meadows often become a necessity to juvenile sage grouse as a sole source of desired food species. Hens and chicks congregate only on these portions of meadow having some typical meadow vegetation. Bare areas or water sources without desired vegetation are ignored. The meadow areas are used almost exclusively by the hens and chicks, but in dry seasons a few males may be observed feeding there.

The heavy and continuous use of sagebrush as a food for sage grouse is understandable because of the harsh climate which they inhabit.[89] Sagebrush is an evergreen shrub with a high digestible nutrient content and is practically the only plant food available throughout the year in parts of Wyoming regardless of snow conditions or drought.

In studies conducted in Montana, the contents of 35 crops of sage grouse were analyzed during the summer.[100] It was found that sagebrush (mainly big sagebrush) and dandelion (*Taraxacum officiuale*) made up over two-thirds of the crop contents. Sagebrush and three genera of forbs together composed 94.6 percent of the samples. It was observed that leaves and flower clusters of sagebrush and dandelion comprised 79.4 percent of the crop contents.

In Wyoming, Patterson reported that only during summer does sagebrush compose less than 80 percent of the food volume consumed by sage grouse.[89] Volumes observed for sagebrush were 86.5, 44.9, 80.7, and 99.7 percent for spring, summer, fall and winter, respectively.

(2) *Cover*: Sage grouse habitat is predominantly a sagebrush association. Sagebrush and other associated shrubs are used as cover for nesting, rearing broods, loafing and roosting. Klebenow[101] found that in mixed stands of big sagebrush (*A. triventata*) and three-tip sagebrush (*A. tripartita*) in Idaho, sage grouse preferred the three-tip site for nesting with 91 percent of the nests occurring there. In areas with little shrub cover, sage grouse nest in the moderately dense portion, but not in the very dense parts.[102] Hens did not nest in areas of tall, dense sagebrush with little understory. The average density of shrubs in nesting vicinities was 18 percent. No nests were found where shrub cover exceeded 35 percent or where sagebrush cover was greater than 25 percent.

Grouse nests are frequently placed under a sagebrush limb or between two adjacent clumps of sagebrush, but rarely a nest is built on open ground with no cover. The average height of sagebrush at nesting sites was 14 in. in Wyoming[89] and 17 in. in Idaho.[101]

Nesting birds and adult males tend to select areas with a moderate amount of shrub cover, but hens with broods choose sites with less shrub cover since the preferred forbs are usually more abundant there. Food plants develop along an elevational gradient and broods follow the same gradient in their summer movements. The most important variable in the discrimination between brood and nonbrood habitat is the sagebrush density. Broods occupy sites with fewer big sagebrush plants. The crown cover of big sagebrush on sites where broods are found was 8-1/2 percent as compared to 14.3 percent cover for adult birds. Few broods are found in areas with greater than 31 percent shrub cover.

In the dry part of the year, the sage grouse begin to form large flocks in the vicinity of green meadows and water holes. Sagebrush, willows, tall grass or uncut fields of hay serve as nesting cover in summer.[90] In the fall, sage grouse leave the higher meadows or fields and return to the sagebrush prairies. They obtain water by daily movements to streams, springs, or marshy meadows. They tend to choose the taller sagebrush in draws and gullies and along stream beds for the mid-day resting stops. At night they choose areas of smaller and more open stands of sagebrush for roosting. The sagebrush serves no function other than cover as the birds neither roost nor rest on the branches, but merely squat on the ground in openings or at the base of bushes.[89]

d. Effects of sagebrush control: Sagebrush is considered a part of the climax vegetation in many areas of the West. In some areas it has increased due to the influence of grazing until it is the dominant vegetation of a site. In adjoining pastures, or pastures on similar sites, the productivity of sagebrush may vary from about 10 percent to 55 percent or more of the total production, depending on the condition of the range.[103] On pristine areas in Idaho, sagebrush made up 2 to 14 percent of the total productivity over a 5-year period on three soil types.[104] These data suggest that, under conditions of no use or proper use by livestock, the density of sagebrush in many areas should not exceed 15 percent of the canopy cover. Over utilization by livestock has upset the delicate balance between grasses and sagebrush in many areas, resulting in dense stands of brush.

As mentioned earlier, sage grouse make little, if any, use of the tall, dense stands of big sagebrush with little understory.[101] The variety of sites used by sage grouse for strutting grounds suggests that improvement of the presently occupied range can provide opportunity for greater numbers of mature males to set up strutting territories and adjacent nesting areas.[90] New strutting areas can be created by fire or by using mechanical means to make openings of 1/4 to 1/2 acreas in dense stands of sagebrush. Sage grouse moved from old strutting grounds to newly cleared patches of ground created by bulldozing or fire.

Higby[105] reported on a sagebrush clearing project in Wyoming in which approximately 12,000 acres were sprayed with 2,4-D over a 5-year period, and 80 to 90 percent control was obtained. About 1,000 sage grouse used the treated and adjacent areas for wintering prior to treatment. The year spraying was completed, no grouse were observed in the area. The year after spraying stopped, birds began using the first area sprayed and the number of birds increased yearly thereafter. Strutting ground counts by years in the treated area, beginning the year spraying was initiated, were: 1961-50; 1962-28; 1963-7; 1964-8; 1965-0; 1966-11; 1967-20; 1968-16; and 1969-31.

Three untreated areas located in different directions and about 25 miles from the treated area, showed a large variation in bird count over these years. In 1963, the count was low at all locations, but higher populations were observed in later years. In 1969, the total number of birds on the three untreated areas was essentially the same as in 1961.

Autenrieth[106] reported that, where 90 to 100 percent sagebrush control was obtained on 50-ft strips with alternate strips left unsprayed, sprayed strips provided prime feed areas for a favored brood forb. Grass and dandelion increased on the sprayed area. As broods moved upward in elevation in summer, they congregated on sprayed strips to feed. The sprayed strips were also used for roosting, while the unsprayed strips were used for shade, loafing and escape cover. The increase in grass cover on the sprayed areas utilized enough of the soil moisture in drier summers that the forbs remained green longer in the brushy areas, and late moving birds were located mostly in these areas. Martin[107] found only 4 percent of observed sage grouse on sprayed strips on which 92 percent of the sagebrush was killed. The productivity on the sprayed areas was 80 percent grass and 20 percent forbs, while on the unsprayed area the ratio was 60:40. Favored forage plants for sage grouse were more abundant on unsprayed areas than on sprayed areas, and the number of grouse in the various strips was related to vegetative composition.

Klebenow[102] found that nesting stopped in an area sprayed for sagebrush control, and it had not been initiated again within 3 years, but a new nest was found on an area 5 years after spraying. Nesting sites were most abundant where brush cover was 17 to 18 percent. Broods were affected less by spraying than were nesting birds. Of the potentially good brood habitat, 34 percent were sprayed and 29 percent of the broods were observed within that sprayed area. On the sprayed areas the stand of sagebrush was reduced, but the amount of bitterbrush and other woody species increased. Sagebrush was reduced by burning, but the stand recovered faster on burned areas than on sprayed ones and eventually resulted in an increase in cover. The effectiveness of a spray treatment affects the length of time before an area will recover sufficiently for nesting. A longer time is needed where a high level of control is obtained. Spraying may change the forb composition and make it more suitable for broods even though the total forb abundance decreases.

In areas with little shrub canopy cover, sage grouse nest in the more dense portion, but not in the very dense stands. Klebenow[101] suggested that controlling tall, dense sagebrush and allowing the native forbs and grasses to recover their former productivity could only benefit sage grouse. Something less than complete control of sagebrush would be desirable. On ranges with less than 10 percent shrub cover and where shrubs are low-growing, the best sites for grouse are the depressions and drainages where the shrubs are taller. He recommended that these areas should be left undisturbed. A good sage grouse habitat would be an open stand of sagebrush with a scattering of other shrubs and an understory of perennial grasses and forbs.

Carr and Glover,[108] reporting on the effects of block and strip spraying using 50-yd strips, found that 1-1/2 years after spraying, sagebrush control did not affect strutting grounds or activities, nor nesting density or success. Nests were found on sprayed and unsprayed areas, but in the sprayed areas they were relatively close to the unsprayed areas. Block-sprayed areas were avoided except for strutting. Areas sprayed in 50-yd strips had no obvious affect on the distribution or movement of adult grouse.

Reeher reported that in Oregon the sage grouse use on big sage range was reduced by spraying or spraying and seeding.[109] Indications were that continuous big sage areas are marginal grouse habitat, and that the loss of habitat by spraying is small.

5. *Chukar Partridge*: The chukar partridge is found throughout most of the study area. However, the bird is not as closely associated with sagebrush as is the sage grouse. Very limited data are available concerning the effects of sagebrush control on the chukar.

Reeher reported that 2,4-D spray projects on good chukar habitat did not reduce the chukar use of the areas.[109] There were some indications that spraying increased the chukar use. At the initiation of the study it was thought that killing sage cover in chukar habitat would be detrimental to the bird population. However, that hypothesis was not substantiated by the results obtained. Figure 12 shows the land use by chukars in the sprayed and control areas based on pellet counts. Spraying was carried out in 1963, and the land use by the birds was greater in the treated area every year except 1965 than in the control area. The low counts in 1965 through 1967 reflected a general decline of chukars throughout the area where the tests were conducted. The amount of the difference in use of the two areas in 1964, 1966, 1967, and 1968, was much greater than the difference observed in 1963, the year the area was sprayed.

In the test area, winter cover for the chukars was juniper trees, patches of aspen (*Populus sp.*), wild current (*Ribes sp.*), mountain mahogany (*Cercocarpos ledifolius*), rose, clematis and mock orange (*Philadelphus lewisii*). Some of the individual plants of those species were killed by 2,4-D spraying, but most survived.

6. *Elk*: Elk are present in various sections throughout the study area. Rouse reported that elk (*Cervus canadensis*) consumed about 90 percent forbs in their diet during the summer in the Gravelly Mountains in Oregon.[109] The major forbs utilized were sticky geranium (*Geranium viscosissimum*), mule's ear (*Wyethia sp.*), pussy toes (*Antennovia sp.*), groundsel (*Senecio sp.*), and forget-me-not (*Myosotis alpestris*).

In the winter, grasses and sedges comprised 90 percent of the contents of three rumen samples, but examination of feeding sites showed heavy use of browse (55 percent of plant use). The heavy use of browse was recorded over a 10-day period of severe cold and heavy snow cover. Three-tip sage (*Artemisia tripartata*) was estimated to account for 49 percent of the observed plant use.

Other studies have confirmed high usage of forbs in the summer by elk.[110-112] By contrast, Morris and Schwartz reported that grass predominated in the diet of elk during the summer as well as during other months of the year, on a range where grasses comprised about 79 percent of the vegetation.[113] However, stomach samples taken in August contained a large quantity of forbs, and June and July samples contained significant amounts of forbs. Mackie reported that about one-half of the browse use

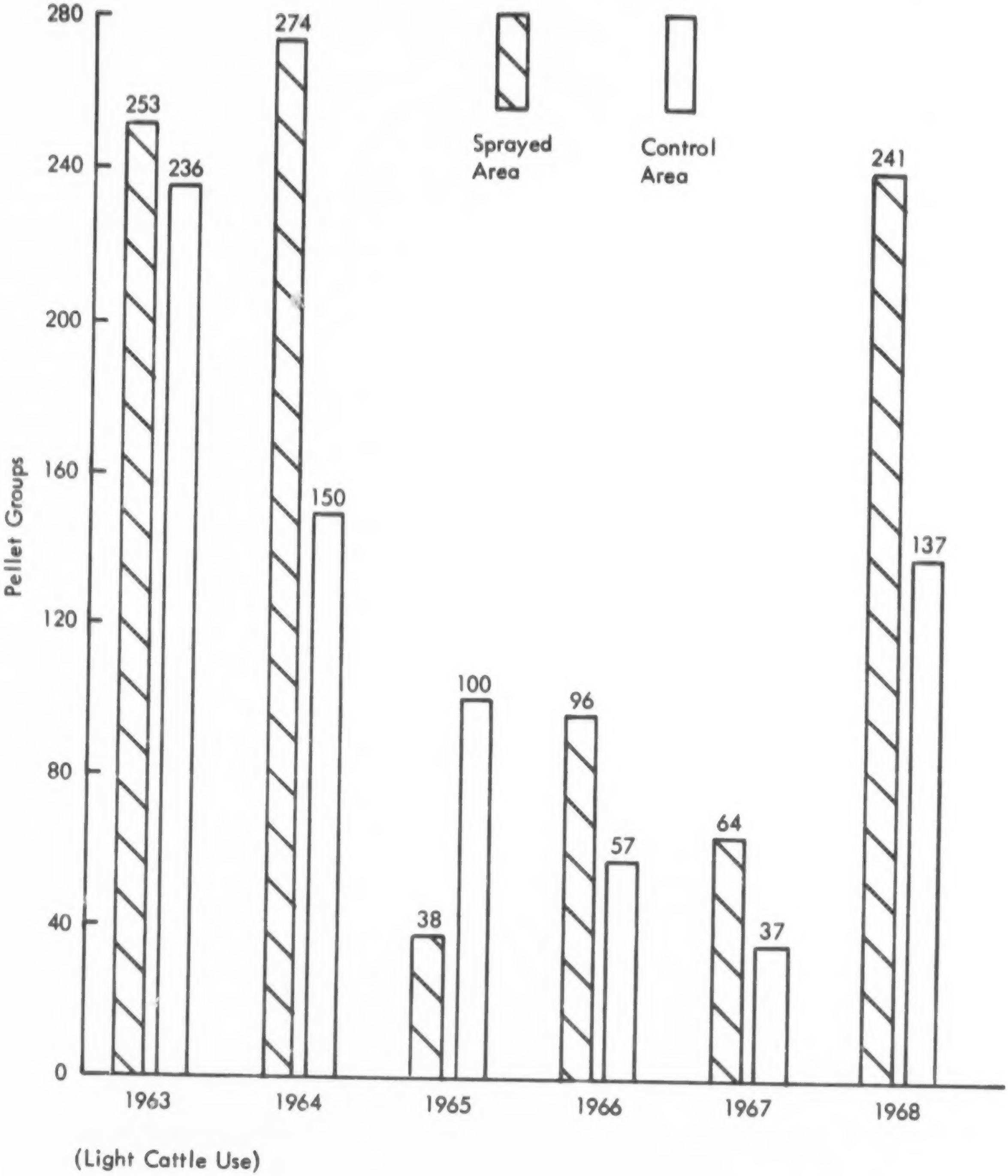

Figure 12 - Land Use By Chukar Partridge on 2,4-D Sprayed and Control Areas

by elk in winter was on big sagebrush, Artemisia tridentata. Browse use, however, was minor as compared to grass use (only 17 percent of plant use).

7. Moose: The moose is usually a browser even in summer. However, Knowlton concluded that forbs made up 70.6 percent of 6,770 instances of plant use recorded during the summer in the Gravelly Mountains in Montana.114/ Sticky geramium alone provided 64.2 percent of all instances of use recognized. The high usage of forbs was apparently related to unusually high precipitation during the summer study period. Similar studies made by Peek in the same general area, during dryer summers, showed that the moose there had a marked preference for willow.115/

8. Bighorn Sheep: Bighorn sheep have been studied to determine their feeding habits. Schallendberger examined 67 feeding sites of the animals during winter in the Sun River Area of Montana. He found the mean percentages for instances of plant use were 36, 21, and 43 for grass and grass-like plants, forbs and browse, respectively. Fringed sagewort was a frequently used browse species.

In a study of the Sun River area of Montana, Couey concluded that grass constituted the bulk of food on the winter for bighorn sheep.116/ He also observed that Artemisia frigida seemed to be a preferred food, and that it was commonly consumed in the winter.

9. Rabbits: Jack rabbits and cottontails occur throughout most of the study area.

In one study, there were no consistent differences between the rabbit use for areas where sagebrush was controlled, and untreated areas.109/

In one other area, there was a consistently lower rabbit use on rehabilitated sites than on control sites. These results were attributed to winter conditions. The test area was located on a high plateau that is usually snow covered during part of the winter. During those periods, rabbits would have to move out of the sprayed areas into surrounding brush areas in search of food and cover. No such movement would be necessary in the untreated control area.

G. Comments

From the data given in the preceding paragraphs (1-9) concerning various species of wildlife that inhabit the sagebrush rangelands, it is apparent that forbs and browse, including sagebrush, play a role of importance to the survival of those animals. Any program which removes or drastically reduces those forage classes, or areas occupied by those species, possibly could be detrimental to their welfare.[48] A drastic reduction of certain forbs on summer ranges could adversely effect antelope, sage grouse, mule deer, whitetail deer, elk, and possibily moose under some conditions. The elimination of sagebrush on winter ranges probably would be most detrimental to sage grouse, antelope and mule deer. However, there are some indications that whitetail deer, elk, and bighorn sheep also could be adversely affected.

Many different wild animals graze on sagebrush sites. Elk graze primarily on grasses and forbs[83] and use little if any sagebrush. Control of sagebrush in Jackson Hole, Wyoming increased the frequency of occurrence of elk grazing on the treated site as compared to untreated.[110] A study in Utah showed that the blacktailed jackrabbit grazed big sagebrush during the winter.[111] The grazing preference of jackrabbits was similar to sheep, i.e., they prefer green grasses and forbs, but will go to sagebrush and rabbitbrush during the dormant season.

A good balance of browse and herbaceous plants is desirable.[79] Even with ample browse, an area may not have enough grasses and forbs to provide succulent forage in the critical periods of late winter and early spring.

Many areas now support vegetation that do not provide satisfactory forage or watershed protection. Such areas include inter alia dense stands of sagebrush supporting few perennial grasses and forbs. On such areas, undesirable vegetation must be destroyed or greatly reduced to allow establishment of desirable species. The method used need not completely eliminate the competing plants, but should thin enough to minimize direct competition for moisture.

Big sagebrush is desirable on most big game and livestock ranges, and especially on sage grouse range. However, where big sagebrush has usurped the site and excluded understory species, the stand must be thinned to permit establishment of grasses and forbs.

Big sagebrush is abundant in protein, but the foliage contains considerable amounts of aromatic oils which reduce palatibility somewhat. It is an important winter forage on foothill areas for big game and livestock in Utah. Its value is enhanced by its unusually rapid growth and exceptional ability to spread naturally from seed. Since wildings and seedlings are transplanted easily, big sagebrush can be used widely for stabilizing gullies and eroding spots on hillsides.

Some ranges, where associated grasses and forbs have been grazed out, have become closed stands of sagebrush. These closed stands must be thinned, and adapted grasses and forbs seeded to provide a suitable and balanced cover.[79]

Ranges with some remnants of desirable grasses will improve rapidly after sagebrush control. Nearly a twofold increase in forage was obtained after treating range in fair condition and fourfold increase on poor condition range.[117]

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VIII. HERBICIDES IN AQUATIC ENVIRONMENTS

A. Sources of Herbicides

Environmental contamination has been classified under two general categories: intentional (direct) application and unintentional (indirect) contamination.[1] Utilizing this basic concept, Ware and Roan[2] developed a classification specifically for aquatic environments. In their classification many of the sources that originally were classified as "unintentional" were changed to "intentional." This classification was justified because pesticides are in fact knowingly added to the aquatic environment. The classification is shown in Table XIV.

TABLE XIV[2]

SOURCES OF PESTICIDES IN THE AQUATIC ENVIRONMENT

A. Intentional introduction

1. Control of objectional flora
2. Industrial wastes
   a. Pesticide manufacturers and formulators
   b. Food industry
3. Disposal of unused materials
4. On-site field cleaning of application, mixing and auxiliary equipment
5. Disposal of commodities with excessive residues
6. Decontamination procedures

B. Unintentional introduction

1. Drift from pesticide applications to control objectional flora.
2. Secondary relocation from target area via natural wind and water erosion.
3. Irrigation soil water from target areas.
4. Accidents involving water-borne cargo.
5. Application accidents involving missed targets or improper chemicals.

This classification is applicable, in part, to 2,4-D herbicide used to control sagebrush within the study area. Some of the sources listed would be more applicable than others because of arid conditions, lack of major industrial operations, relatively low population density, and various other factors characteristic of the area.

B. Entry Into Aquatic Environments

The principal avenues of 2,4-D entry into an aqueous system are: (1) runoff from treated soil, (2) inadvertent application over a body of water while treating terrestrial plants, (3) use for the control of aquatic weeds, and (4) accidental contamination.

1. Runoff from treated soil: Barnett et al.[3/] measured the 2,4-D losses from bare soil runoff on a 5-7 percent slope. Thirty-five percent of an iso-octyl ester formulation of 2,4-D was lost off a 35-ft plot in 1/2 hr, and as the rate of 2,4-D application doubled, the amount of runoff more than doubled. The maximum concentration from a 4.4 lb/acre application was 4.2 ppm. The concentration in runoff tended to decrease with time. The amount of 2,4-D lost in runoff did not increase with increase in slope length from 35-75 ft, a fact which suggests that water from upslope was percolating into the soil downslope. Ester formulations were more subject to removal in runoff than were amine salts. The average loss of 2,4-D in runoff was 13 percent for esters and 4 percent for amines in a 1-year frequency storm.

To determine the amount of 2,4-D that would enter the water environment during a typical application, Aldhous[4/] measured the 2,4-D in drainage furrows across a slope that was sprayed at the rate of 4 lb/acre. The site was marshy and there was no runoff from the soil surface, only drainage from the high water table. The concentration of 2,4-D detected in the water (minimum detectable concentrations of 0.005 ppm) the day before spraying and 1, 2, 4, 7 and 28 days later was 0, 1.5, 1.6, 2.0, 1.6 and 0 ppm, respectively. The concentrations observed were probably as high as can be expected without runoff from rainstorms.

The concentration of 2,4-D in irrigation water was measured by sampling at stations 1/4, 1-1/4, 2-1/2, 5, 7-1/2 and 10 miles below the point of actual field application. Where high concentrations of 2,4-D occurred at the first two stations, there was a dissipation with distance from the starting point. When low levels of 2,4-D occurred at the first two stations, the average concentration at successive stations was relatively constant with only a slight dissipation. The maximum concentration of 2,4-D at any sampling station in 11 and 18 canals was below 50 ppb; in six canals it was between 50 and 100 ppb; in the other two it was 138 and 213 ppb. The 213-ppb concentration occurred below an overlapping application of 3 lb/acre of 2,4-D. In most canals the concentration of 2,4-D declined with distance. There was not a measurable amount of 2,4-D in the water arriving at the stations after the dye marker, which was applied immediately after the herbicide treatment, had passed.5/ Rates of 2,4-D application varied from 1.4 to 2.5 lb/acre.

2. Inadvertent application over water while treating terrestrial weeds: In one study6/ 2,4-D was applied at a rate of 1.9 to 3 lb/acre for weed control along the banks of a canal. Maximum concentrations of 25-61 ppb of 2,4-D were detected in the water after application, and negligible concentrations of the herbicide were found after the water traveled a distance of 20-25 miles.

It was concluded that the low concentration of herbicides observed in the irrigation water likely would not be hazardous to crops or animals. Further, levels of 2,4-D were reduced to traces or nondetectable quantities within 30-60 min.

3. Application for the control of aquatic weeds: The selective herbicidal properties of 2,4-D were discovered in 1944, and research on its use for aquatic-weed control was initiated in 1947 by several government agencies.7/ The herbicide, 2,4-D, has been reported to be the most commonly used chemical for the effective control of rooted submersed, rooted, immersed, floating, and marginal weeds in ponds, lakes, irrigation ditches, and canals.7/ When used for aquatic plant control, 2,4-D is applied as the water-soluble sodium, potassium, ammonium, or amine salts, or as short chain alkyl esters such as methyl, propyl, butyl, or vityl, or as heavy nonvolatile esters. The esters are usually applied as granules, absorbed onto clays, or formulated in emulsifiable liquid concentrates in different oils and organic solvents. Application rates range from 20-100 lb of 2,4-D acid equivalent per acre of water.7/

Averitt reported that the concentration of 2,4-D in the water from a 4 lb/acre application for water hyacinth control was 739, 802, 446 and 74 ppb daily for the first 4 days after application.8/ The concentration declined gradually to no detectable 2,4-D after 102 days. A second test showed a maximum concentration of 600 ppb in 3 days, 80 ppb the 4th day, and then a gradual decline.

In tests in which 2,4-D was applied at 1-10 lb/acre on water hyacinths growing in water from 1-7 ft deep and at various times of the year, the concentration of 2,4-D in the water varied with the rate applied, water temperature, water depth, and the time lapse after treatment. The maximum concentration of 2,4-D applied at 4 lb/acre in 1-ft depth pools was 831 ppb. At the 4 lb/acre rate, the concentration of 2,4-D was reduced by 58 ppb for each 2-ft increase in water depth, 115 ppb for each 10-degree increase in temperature about 60°F, and 53 ppb for each 7-day interval after application. With a water temperature of 61°, 2,4-D concentration declined very little in 28 days. When the water temperature was 75° or above, the 2,4-D concentration after 28 days was generally 10 percent or less of the maximum concentration.[9]

Frank and Comes[10] measured a maximum concentration of 2,4-D of 0.067 ppm 18 days after applying granular 2,4-D butoxyethanol ester to pond water at a concentration of 1.33 ppm. Low concentrations were found in water for 24 days and in soils for 55 days. The concentration in the top 1 in. of soil the day after treatment was 4.96 ppm, which declined to 0.10 ppm by 56 days. The low concentration in the water could be due to absorption by weeds. The amount of 2,4-D salt or esters sorbed on bentomite, illite or kaolinite varied from 0.02 to 0.14 mg/g. Esters of 2,4-D were hydrolyzed in lake water to the acid in 9 days, but persisted for 120 days under aerobic conditions. 2,4-D was biologically decomposed in lake mud and disappeared completely in 35 days in a previously treated lake, and in 65 days in untreated water. 2,4-D did not disappear from lake mud that was treated with sodium azide.[11]

Smith and Isom[12] found that less than 1 ppb of 2,4-D in pond waters treated at rates of 40-100 lb/acre for watermilfoil control at eight out of nine sampling stations. They concluded that 2,4-D did not produce adverse effects on water quality. De Marco et al.[13] reported 2,4-D in river water was biologically degraded under warm-aerobic, cold-aerobic and cold-anaerobic conditions. Under warm-aerobic conditions 2,4-D was degraded in 6 days; under cold-anaerobic it took 55-80 days. Low-oxygen conditions had more effect on rate of degradation than temperature had.

Cope[14] treated ponds with the PGBE ester of 2,4-D at concentrations of 0, 0.1, 0.5, 1.0, 5.0 and 11 ppm, active ingredient. The residues levels in the water dissipated rapidly. The 5-ppm and 10-ppm concentrations persisted for 2 and 3 weeks, respectively. In the 10-ppm pond, the aquatic weeds were controlled by 80-100 percent. 2,4-D in the vegetation was almost completely dissipated in 3 months. 2,4-D was detectable in bottom sediments for 44 and 94 days, respectively, at the 5- and 10-ppm rates.

4. Accidental contamination: Application accidents involving missed targets could account for the unintentional introduction of herbicide into the water environment. Aerial spraying is the most common method of herbicide application, and once the material is released into the atmosphere, the exact behavior of the aerosol cannot always be predicted or controlled precisely. Herbicide aerosols occasionally drift from the target area onto waterways like streams, rivers, ponds, lakes, and irrigation ditches.

In the study areas, it is general practice to dispose of empty herbicide containers by crushing them and then burying the flattened containers in a landfill.[15] The containers are usually drained of any remaining liquid; however, a residue of the herbicide undoubtedly remains on the inside surfaces. It is possible that some 2,4-D eventually could find its way into a water system. Rain or snow could carry the chemical into a stream, reservoir, or other body of water; it appears, however, that such disposal practices do not constitute major sources of water pollution. Unquestionably better disposal techniques could be developed and implemented.

C. Impact of 2,4-D Pollution on the Water Environment

It appears that 2,4-D is relatively nontoxic in an aquatic environment. In the direct application of 2,4-D at 2 lb/acre across running streams in Alaska, Sears and Meehan[16] reported no mortality to fish. The concentration of 2,4-D in water and fish samples was below levels considered toxic. The application of 2,4-D to ponds at a rate of 100 ppm had no apparent effect on the hardiness or reproductive ability of say mesquito larvae.[17] There was little uptake by fish from applications of 40-100 lb/acre of 2,4-D butoxyethanol ester granules, but there was uptake by mussels. No adverse effects were observed upon aquatic fauna by high application rates of 2,4-D. Macek[18] reported no apparent effect on scud (Gammarus fasciatus) in a 96-hr TL_{50} test with concentrations of 2,4-D amine up to 100 mg/liter. Ware and Roan[19] reported a decrease in CO_2 fixation by phytoplankton during a 4-hr exposure to some ester formulations of 2,4-D at 1 ppm, but not by the acid or amine formulation used. Oysters and clams held in the center of a plot treated with 2,4-D at 30 lb/acre for watermilfoil control had a residue of 3.5 to 3.7 ppm.[20] Bluecrab and fish had residues of 0.3 and less than 0.8 ppm, respectively. The chromotropic acid color test, which gives a characteristic color to any substance that breaks down into formaldehyde, was used to determine 2,4-D.

Cope[21] reported that bluegill exposed to the propyleneglycolbutylether (PGBE) ester of 2,4-D developed pathological symptoms within a few days. Glycogen was removed from the liver, and glycoproteins were deposited in the circulatory system, causing stasis in some vessels. This pathology lasted more than 3 months. No residues of 2,4-D were found in whole-body residue studies of bluegill exposed to 2,4-D PGBE ester for 30 days at a concentration of 10 ppm.[22] The time of bluegill spawning was delayed 2 weeks in ponds treated with 5 and 10 ppm of 2,4-D PGBE. Reproduction apparently proceeded normally and resulted in an average hatch of fry. High-treatment groups of bluegill ended the experiment with small numbers of larger fish, whereas the low 2,4-D treatment groups had more fish of small size. Increased fish size was probably due to the greater amounts of available food. The data available on the effects of herbicides on the reproduction of fish do not appear to prove that quantity or quality of eggs, hatching of eggs, or quality of offspring are seriously affected by exposure of adults to weed killers.[23]

Rodgers and Eller[24] found no pathological intoxication in rainbow trout, bluegill or channel catfish by exposure to C^{14}-labeled 2,4-D butoxyethanol ester in contact baths at concentrations of 0.3 and 1.0 mg/liter. The fish did not absorb any detectable amount of 2,4-D or metabolites after an initial absorption period of 3-4 hr. The residues in individual organs reached a maximum in 2-3 hr, and rapidly diminished thereafter, except in the gall bladder. The residues were associated almost exclusively with the bile. The maximum concentration of radioactive material in the bile of trout, catfish and bluegill was 105, 268 and 311 µg/g of organ, respectively, in the bath containing 1.0 mg/liter, and 26, 659 and 29 µg/g in the 0.3 mg/liter bath. Rodgers and Stalling[25] reported water was more important than feed as a source of fish contamination with 2,4-D. Bluegill in water containing 2 mg/liter of C^{14}-labeled 2,4-D had body residues of radioactive materials of 0.20 µg/g, while fish fed a diet containing 2 mg/kg of labeled 2,4-D retained whole body radioactive residues of 0.005 µg/g. The principal location of radioactive material after 4 weeks' exposure to C^{14}-labeled 2,4-D in water was in the bile with a concentration of 55 µg/g.

Grant and Mehrle[26] injected male goldfish with spermiation gonadotrophin after a 6- to 8-day exposure to 2,4-D at 700, 300, 150, 70 and 0 µg/liter. The spermiation response occurred in all treatment groups, but the magnitude of response was proportionately less as the concentration increased above 70 µg/liter, the no-effect level. A treatment of 2-4 lb/acre of 2,4-D in 1-ft depth water may interfere directly with spawning in goldfish and could be more detrimental to less hardy species.

Cope[27] treated ponds containing bluegill with 0, 0.1, 0.5, 1.0, 5.0 and 10 ppm of 2,4-D PGBE. Fish mortality at the three highest rates was 19, 0.30 and 0.16 percent, respectively. There was no mortality below 1.0 ppm. 2,4-D residues were detectable in the fish only at the 5- and 10-ppm concentrations. The higher the 2,4-D concentration, the greater the fish growth. Fish in 10 ppm of 2,4-D attained twice the length and three times the weight of the control. Intermediate rates gave intermediate increases in fish growth. There was no difference in number of offspring. The increase in growth was probably due to an increase in food made available by control of aquatic plants or by a decrease in fish population in the pond. The single exposure of 2,4-D at 10 ppm, while resulting in severe pathological changes, was followed by eventual complete recovery.

Additional data on 2,4-D residues and toxicities in aquatic species are shown in Table XV.

TABLE XV

2,4-D RESIDUES AND TOXICITIES FOR AQUATIC SPECIES

A. 2,4-D Residues (μg/g) in Fish Tissue

Tissue	Bluegill	Channel Catfish	Largemouth Bass
Blood	68	29	6
Brain	97	27	5
Eggs	76	--	6
Storage fat	--	--	3
Striated muscle	40	6	1
Lateral-line muscle	30	13	3
Posterior kidney	88	35	4

B. Acute Toxicity of 2,4-D to Aquatic Species (dimethylamine salt)[30]

Species	Weight	Temp.	24 hr	96 hr
Bluegill	1 g	17°C	154,000-262,000	125,000-177,000
Fathead minnow	1 g	17°C	389,000	335,000
Coho salmon	1 g	17°C	154,000	125,000
Channel catfish	1 g	17°C	154,000	125,000
Largemouth bass	1 g	17°C	154,000	125,000

C. Toxicity of 2,4-D PGBE to Aquatic Species[22]

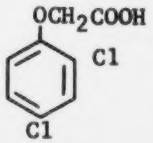
Species	48-hr EC_{50} Values (ppb)
Rainbow trout	1100
Bluegill	900
Stonefly nymphs (*Pteronarchys californicus*)	1800
Water flea (*Daphnia pulex*)	3200
Water flea (*Simocephalus serrulatus*)	4900

D. Degradation of 2,4-D in an Aquatic Environment

The biodegradation of 2,4-D apparently is a function of the size and nature of the microbial population of the aquatic environment.[29] About 68 percent of the 2,4-D concentration is used in the respiration process, whereas 32 percent is incorporated into the microbial cells as a reserve energy source. Results of studies indicate that the biodegradation of the herbicide follows zero-order kinetics. The rate of biodegradation is dependent on several factors. One is the time necessary for the enzyme system to become acclimated to the chemical, and the second is the effect of age of the acclimated microorganisms on the rate. As the rate decreases, the acclimation period increases until it reaches a stabilization point. Therefore, new additions of 2,4-D degrade faster than previous ones, provided the stabilization point has not been reached. The natural condition of the aquatic environment also is a factor. As an illustration, 65 days were required to detoxify 2,4-D in bottom mud of a lake, and in contrast only 12 to 14 days were needed for degradation in soil. The conditions in water may not be as conducive to the biodegradation of herbicides as those in soil.[31] The metabolism of 2,4-D was much slower in water than in a terrestrial environment.

DeMarco et al.[32] showed that a period of 12-14 days was needed for the acclimation of aquatic microorganisms to biodegrade 2,4-D. After the initial lag period, the rate of biodegradation of 2,4-D increases to a maximum value dependent on a given concentration of microorganisms. When the ratio of microorganism concentration to 2,4-D concentration was held constant, constant oxidation rates were observed, suggesting that the enzyme systems were saturated with substrate. Therefore, substrate concentrations were not a limiting factor, a fact further substantiating the appropriateness of the zero-order kinetic model.

The biodegradation of 2,4-D appears to follow the stoichiometry illustrated by the following equation.[29]



$$+\ 7.5O_2 \rightarrow 8CO_2 + 2H_2O + 2\ HCl\ .$$

To recapitulate, these variables must be considered in studying the biodegradation kinetics of 2,4-D: (1) microorganism concentration, (2) substrate concentration, and (3) the ratio of microorganism concentration to substrate concentration.[29] These three variables affect the rate at which 2,4-D is converted to carbon dioxide, water, and hydrochloric acid.

E. 2,4-D Content of Water in Western States

In October 1966, the U.S. Geological Survey began a program of monitoring pesticides in the streams of the western United States.[33] The program has continued to date. One of the herbicides included in the surveillance program was 2,4-D.

Table XVI shows the results of 2,4-D analysis of water samples from 13 sampling stations located within or near the study area. From October 1966 through June 1971, a total of 383 samples were analyzed for 2,4-D content, and only with 68 of the samples was it possible to detect any of the herbicide (about 17.8%). The concentration of 2,4-D ranged from 0.00 to a high of 0.99 μg/liter. The amounts of 2,4-D reported are far below the 100 μg/liter concentration permissible in public water supplies.[34] There were no positive samples from November 1970 through June 1971.

Location	1968			1969												1970												1971					
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Irrigation Network No. 63, Yuma Main Canal, Yuma, Arizona	0.00	0.00	0.00	0.14	0.00	0.24	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Network No. 71, Gila River Above Diversions, at Gillespie Dam, Arizona	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Irrigation Network, No. 24, Arkansas River Below John Martin Reservoir, Colorado	0.00	0.00	0.00	0.00	0.00	0.00	-	-	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Irrigation Network, No. 79, Humboldt River Near Rye Patch, Nevada	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Network No. 66, Green River at Green River, Utah	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00
Irrigation Network No. 5, Yellowstone River Near Billings, Montana	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Network No. 15, James River at Huron, South Dakota	0.16	0.16	0.43	0.00	0.00	0.00	0.15	0.14	0.13	0.11	0.00	0.04	0.26	0.03	0.07	0.05	0.00	0.19	0.06	0.05	0.39	0.38	0.14	0.11	0.04	0.00	0.00	0.00	0.00	-	-	-	-
Irrigation Network No. 54, Pecos River Near Artesia, New Mexico	0.00	0.00	0.15	0.10	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Network No. 97, Snake River at King Hill, Idaho	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	-	0.06	0.03	0.05	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.04	0.00		0.00	0.00	0.00		0.00	0.00	-
Irrigation Network No. 102, Columbia River at the Dalles, Oregon	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00		0.00	0.00	0.25	0.00		0.00	-	-	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00
Irrigation Network No. 88A, Feather River Near Oroville, California	0.00	0.00	0.99	0.06	0.00	0.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Irrigation Network No. 86A, Sacramento River at Verona, California	-	0.00	0.22	0.00	0.00	0.00	0.00	-	0.00	0.00	0.02	-	0.04	-	0.00	0.00	-	0.07	0.00	0.02	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	-
Irrigation Network No. 34, Yakima River at Kiona, Washington	-	0.00	0.00	0.00	0.00	0.00	0.20	0.24	0.21	0.18	0.09	0.09	0.04	0.00	0.05	0.04	0.04	0.00	0.05	0.42	0.15	0.16	0.18	0.00	0.04	0.00	0.00	0.06	0.00	0.00	0.00	0.00	

TABLE XVI
2,4-D CONTENT OF SELECTED STREAMS IN THE WESTERN UNITED STATES (Micrograms/Liter)

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IX. TOXICITY AND HAZARD OF 2,4-D TO ANIMALS AND MAN

A. Introduction

Herbicides have been employed to control undesirable vegetation for many years. Chlorinated phenoxyacetic acid and closely related compounds have proven to be some of the most effective weed and brush control agents. The compound, 2,4-D (2,4-dichlorophenoxyacetic acid), presently used to control sagebrush on rangelands is a prototype of that group of herbicides. Because of the long history of use of 2,4-D, considerable data concerning the toxicity of the compound are available. In the following sections, the toxicity and hazard to both animals and man are discussed.

B. Toxicity and Hazard to Animals

Among the first to conduct toxicity studies with small animals using 2,4-D was Bucher in 1946.[1/] In experiments with mice, rats, rabbits, and dogs, temporary myotonia lasting from 8-24 hr or more was observed following a single injection of 150-250 mg/kg of the compound. Repeated injections of smaller amounts, 50-100 mg/kg/day, for 90 days failed to elicit either a characteristic chronic syndrone or a striking histological picture. Normal litters were born to female mice during the course of the treatment. Also, repeated injections of 2,4-D did not alter the rate of growth of two transplanted mouse sarcomas.

Toxicological studies with various preparations of 2,4-D were reported by Hill and Carlisle in 1947.[2/] In acute oral studies, it was found that the LD_{50} for mice to be 375 mg/kg; for rats, 666 mg/kg; for rabbits, 800 mg/kg; and for guinea pigs, 1,000 mg/kg. A dose of 21.4 mg/kg was administered to a monkey without serious after-effects. A dose of 428 mg/kg caused nausea, vomiting, lethargy, muscle incoordination, and head drop. All species tested reacted similarly, and there was no significant difference in potency between crude and purified preparation, or between the sodium or ammonium salts. Death resulting from large doses apparently was because of ventricular fibrillation. If death was delayed, myotonia, stiffness of extremities, ataxia, paralysis, and coma were observed.

In subacute studies, it was observed that severe intoxication occurred in dogs after six daily intravenous injections of 25 g/kg of 2,4-D. Rats were fed a diet containing 1,000 parts per million (ppm) of 2,4-D for a month without harmful effects, and guinea pigs tolerated 10 doses of 100 mg/kg during a 12-day trial. In addition, the inhalation of the sodium salt of the herbicide failed to cause systemic effects in guinea pigs.

There was some evidence of chronic intoxication in rats. They exhibited visceral congestion and edematous kidneys with degenerative changes in the tubules. Dogs showed hepatic damage with central degeneration and congestion.

In 1948, the results of studies carried out on chicks with alkanolamine salt of 2,4-D were reported by Bjorn and Northern.[3] They found the acute oral lethal range to be 380 to 765 mg/kg. When repeated doses (12) were given over a 28-day period, 28 mg/kg/dose was without effect, while 280 mg/kg/dose resulted in a depression of growth. The workers concluded that there was little likelihood of any toxic effects on chickens from 2,4-D used under the prevailing conditions. They pointed out that at a spraying rate of 1 lb of 2,4-D per acre (a normal application rate), a chicken weighing 1 kg would have to consume all the 2,4-D applied on 72 sq ft within a day or two to obtain a lethal dose.

The results of acute and chronic oral toxicity studies on 2,4-D and 2,4,5-T herbicides were reported by Drill and Hiratzka in 1953.[4] Acute oral LD_{50} values of about 100 mg/kg were obtained for both compounds. At that dose concentration, 2,4-D produced definite myotonia accompanied by anorexia and weight loss in dogs. No adverse effects were observed when 2,4-D was fed five times a week for 90 days at dosage levels of 2, 5 and 10 mg/kg. Doses of 20 mg/kg of 2,4-D caused serious effects, and three or four dogs died. Dogs receiving the high doses of 2,4-D exhibited stiffness of the hind legs, difficulty in swallowing, bleeding gums, necrotic changes in the buceal mucosa, and mild liver and kidney changes. There was a significant decrease in lencocyte counts observed terminally in three or four animals. These workers also pastured sheep and cows on forage sprayed with more than recommended amounts of 2,4-D and no adverse effects were observed. In another experiment, a lactating cow was fed 5.5 g of 2,4-D daily for 106 days without ill effects. A demonstrable quantity of 2,4-D was not found in milk from the cow, nor could the herbicide be found in the serum of a calf fed the milk. However, a concentration of 8.4 ppm of 2,4-D was present in the cow's serum, although none was found in the liver, kidney, or fatty tissues.

In 1950, the results of studies with 2,4-D and domestic livestock were reported by Grigsby and Farwell.[5] Alfalfa was sprayed with three different preparations of 2,4-D and horses, dairy and beef cattle, sheep, swine, and chickens were immediately pastured in the freshly treated area. The investigators concluded from the results of the study that none of the 2,4-D preparations had any serious physiological effects upon the livestock involved. They also stated that, since the application rates were two to four times greater than recommended dosage, it seemed that the use of the materials for pasture weed control was a reasonably safe procedure.

The acute oral toxicity of 2,4-D compounds was summarized by Rowe and Hymas.[6] Table XVII is a tabulation of their data.

As shown in Table XVII, the acute oral LD_{50} values for 2,4-D and its derivatives commonly used in herbicide formulations fall in the range of 300-1,000 mg/kg for rats, mice, guinea pigs, and rabbits. Generally, dogs are more sensitive to 2,4-D on a weight basis, and chicks more tolerant to the material. The toxicity to cattle apparently is about the same as the toxicity to ordinary laboratory animals.

The acute oral LD_{50} values obtained were approximately proportional to the amount of active ingredient, and inert ingredients in the herbicide formulations did not appear to contribute to the oral toxicity.

In other studies, amine and alkali salts and esters of 2,4-D were fed to calves, pigs, rats and chickens by Erne.[7] The salts were readily absorbed and completely distributed in the body, but 2,4-D ester was incompletely absorbed and reached only a low level in the plasma and tissues. The highest tissue levels of 2,4-D were found in liver, kidney, spleen and lungs and the level in these organs sometimes exceeded the level found in the plasma. Penetration of 2,4-D into placental tissue of pigs was recorded, but there was little or no evidence of penetration into adipoise tissue or the central nervous system. Elimination of the compounds was rapid, the plasma half-life being about 3 hr in rats, 83 in calves and chickens, and 12 in pigs. The tissue half-life values ranged from 5-30 hr. No retention of 2,4-D was noted in the tissue. There was no accumulation after repeated dosing, and in pigs there was an increase in the rate of elimination after repeated administration. In all species the main excretory route was via the kidneys.

Khanna and Fang[8] traced the metabolism of C^{14} labelled 2,4-D in rats dosed at rates from 1-100 mg/animal. Radioactivity was found in all the organs studied with some accumulation as early as 1 hr after dosing. At the 1-mg dose rate a concentration peak developed after 6-8 hr but decreased thereafter and was nondetectable for 24 hr. At the 80-mg dose the peak occurs at 8 hr and persisted for 17 hr. Extracts of the tissues contained mainly unchanged 2,4-D residues. No radioactivity was found in the expired carbon dioxide. Elimination in urine and feces was dose dependent. At the 1- to 10-mg doses, 93-96 percent of the 2,4-D was excreted unchanged in the urine in 24 hr. At the 20- to 100-mg doses, greater amounts of 2,4-D were found in the second 24-hr period after dosing with a linear decrease in percent recovery with increase in dose. To determine the fate of 2,4-D in dairy cattle, a cow was fed 5 ppm (based on a daily ratio of 50 lb) of 2,4-D for 5 days. No residues were found in the feces or milk during the period of treatment or 2 days thereafter, using a system which would detect a concentration of 1 ppm of 2,4-D. The rumen content of 2,4-D in a fistulated

TABLE XVII

ACUTE ORAL TOXICITY OF 2,4-D COMPOUNDS

Material	Species	Sex	Vehicle	LD50 (19/20 confidence limits) (mg/kg)
2,4-D (2,4-dichlorophenoxyacetic acid)	Rats	M	Olive oil	375 (302-465)
	Mice	M	Olive oil	368 (312-484)
	Guinea pigs	M and F	Olive oil	469 (397-553)
	Chicks	M and F	Olive oil	541 (358-817)
	Dogs (4)		Capsule	Range 100 (25-250)
2,4-D, alkanolamine salts	Chicks (3)		Water (dosage on acid equivalent basis)	Range --- (380-765)
2,4-D, sodium salt	Rats	F	Water	805 (610-1,063)
	Rats (2)		Water	666 ---
	Guinea pigs	M	Water	551 (417-727)
	Guinea pigs (2)		Water	1,000 ---
	Mice (2)		Water	375 ---
	Rabbits (2)		Water	800 ---
2,4-D, isopropyl ester	Rats	M and F	Olive oil	700 (569-861)
	Guinea pigs	M	Olive oil	550 (451-671)
	Mice	M	Olive oil	541 (398-736)
	Chicks	M and F	Olive oil	1,420 (1,127-1,789)
2,4-D, mixed butyl esters	Rats	F	Corn oil	620 (320-954)
	Guinea pigs	F	Corn oil	848 (604-1,1)
	Rabbits	F	Corn oil	424 (252-712)
	Mice	F	Corn oil	Range 713 (500-1,000)
	Chicks	M and F	Undiluted	2,000 (1,350-2,950)
2,4-D, mono, di-, tripropylene glycol butyl ether esters	Rats	F	Corn oil	570 (510-640)

heifer decreased from 3.5 ppm to less than 0.5 ppm in 24 hr, but the concentration remained constant in an artificial rumen, indicating no degradation in the rumen. The reduction in 2,4-D concentration in the rumen might be due to dilution or absorption on the rumen walls.[9] A steer fed the above concentration of 2,4-D eliminated over 88 percent of it in the urine.[10] No 2,4-D was found in the urine 3 days after feeding.

Milk from dairy cows grazing a pasture sprayed with 2,4-D ester at 2 lb/acre contained 0.01 to 0.09 ppm 2,4-D acid during the first 2 days after spraying and lower amounts thereafter. No ester formulation was found. Residues from cows placed in the pasture 4 days after spraying were below 0.01 ppm, the limit of precision of the instrument used.[11] No bound forms of 2,4-D were found in the milk.[12]

Radioactive 2,4-D was administered to sheep in a gelatine capsule at a rate of 4 mg/kg live weight, the calculated maximum daily dose a sheep might eat on a treated pasture. About 15 percent of the 2,4-D was excreted in the urine within 1-1/2 hr after treatment. By 70 hr, 95.8 percent of the radioactivity was excreted in the urine, 1.4 percent in the feces. Radioactivity in the blood reached a peak in 1-1/4 hr, and then decreased rapidly to the background level. All edible tissue contained less than 0.05 ppm. It was concluded 2,4-D is excreted unchanged.[13]

No ill effects were observed in cows grazed on a pasture treated with a 2:1 mixture of 2,4-D and 2,4,5-T when applied at a rate of 2,4-D of 2, 4, or 8 lb/acre. A cow, calf, sheep and sows with pigs were sprayed with 1/2 gal. of the spray mixture with no harmful effects. Cows were given the 2,4-D--2,4,5-T mixture in water at a rate of 2,4-D of 28 mg/5 gal. of water and on the hay at a rate of 26 mg of 2,4-D per day for 41 days with no ill effects. Calves did not show a preference for a weedy pasture sprayed with 2,4-D and 2,4,5-T over an unsprayed pasture.[14]

Dobson[15] sprayed 2,4-D on grassed chicken runs daily for 14 days at normal and 10 times normal dose rates. Egg production was affected the second week of spraying and the following week. There was no effect on fertility, and the progeny reared well. Some of the 2,4-D fed to hens was excreted in their eggs.[16] Eggs injected with 0.5, 5 and 10 mg of 2,4-D per egg resulted in a reduction in hatching of 20-50 percent. None of the chicks hatched were deformed.[17]

Palmer[18] gave daily oral doses of 2,4-D alkanolamine salt to steers for 5 days a week. Signs of poisoning occurred in animals dosed at 250 mg/kg after 15 doses and after 86 doses at 100 mg/kg. No ill effects were recorded at 50 mg/kg after 112 doses. He concluded that cattle could ingest enough 2,4-D from a concentrated solution to produce illness or death, but it would be unlikely that an animal would eat enough over a period of time from grazing to cause serious ill effects. Palmer and Radeleff[19] found no ill effects in cattle from 10 doses of 2,4-D propyleneglycolbutylether ester at a rate of 100 mg/kg, but three doses at 250 mg/kg was toxic. Sheep suffered an 11 percent weight loss during the administration of 481 daily doses of 2,4-D amine at a rate of 100 mg/kg; the ester formula at this dosage rate produced no ill effects. A 250- or 500-mg/kg dosage repeated daily was toxic to sheep. Lisk et al.[20] fed a steer 113.5 mg of 2,4-D in a diet containing 5 ppm of 2,4-D; 100.6 g were excreted in the urine; no 2,4-D was found in the urine 3 days after feeding.

The maximum safe dose of 2,4-D for monkeys is 214 mg/kg.[21]

In short-term trials Bjorklund and Erne[22] found that calves and pigs showed definite but reversible symptoms of poisoning after single doses of 2,4-D of 200 and 100 mg/kg, respectively. Rats did not show any sign of distress after a single dose of 100 mg/kg. Fowl tolerated daily doses of 300 mg/kg in their feed for several weeks without visible effects. Palmer and Radeleff[19] found a gain in growth rate of chicks given 50 mg/kg of 2,4-D ester for 10 days but the growth rate was reduced at the 100 mg/kg or higher rates.

Erne[22] fed five young pigs 500 ppm of 2,4-D for up to 12 months. Although toxic effects were noted and growth rate was affected, none of the pigs died. When 2,4-D was fed to a sow throughout gestation and for 6 weeks thereafter, 10 of her 15 piglets died within 24 hr after birth and the mother was subsequently slaughtered because of abnormalities that developed in her spine. Dosing of pregnant rats with 1,000 ppm of 2,4-D in their drinking water for over 10 months and dosing of their off-spring for up to 2 years did not produce unequivocal signs of toxicity but did lead to retarded growth and increased mortality. Continued administration of 500 ppm of 2,4-D in feed or 1,000 ppm in the drinking water of fowl led to reduced egg production and kidney abnormalities. It was concluded that the chronic toxicity of 2,4-D to their test animals was moderate.

Deer harvested in a forest area treated with 2,4,5-T and 2,4-D accumulated very small amounts in the organs and tissues examined; the highest concentration was 54 ppb in the thyroid. Intestinal concentrations up to 127 ppb in the feces provide abundant evidence of exposure to 2,4-D, but the low levels in most body tissue is evidence of breakdown within the animal or passage through the digestive system.[23] Mule deer given 80 or 240 mg/kg of 2,4-D daily for 30 days showed slight symptoms of toxicity, but there was no loss of weight.[24]

Residues of 2,4-D, applied to sagebrush at 2 lb/acre, were found in sage grouse muscle and brain tissue according to Carr and Glover.[25] Samples of tissue contained 0.3 to 2.7 ppm, and the composite brain sample had 6.0 ppm. However, the method of analysis showed a concentration of 2,4-D of 3.6 ppm in sagebrush samples collected 2-1/2 miles from any sprayed areas, so possibly something besides 2,4-D was being measured. They concluded it was unlikely that sage grouse would be harmed seriously by 2,4-D from sagebrush treatments.

Zielinski et al.[26] measured the disappearance rates of 2,4-D in mice using gas chromatography. The half-turnover rate (t-1/2) value was 4.12 hr. The butyl ester of 2,4-D disappeared from mice bodies faster than the acid. The data suggest 2,4-D is excreted unaltered. Courtney[27] injected 2,4-D at a dosage of 100 mg/kg in female rats. In whole blood, 2,4-D occurred only in the blood serum with a peak of 73 mg/ml in 2 hr. Giving rats pretreatment injections with 2,4-D, phenolbarbital, DDT, lindane, DMSO or chlordane increased the rate of metabolism of 2,4-D by rat liver homogenates.

Pocket gophers fed 2,4-D at a rate of 200 mg/kg live weight showed no deleterious signs. However, the gopher population decreased 87 percent in Colorado[28] and 93 percent in Idaho[29] on areas sprayed with 2,4-D. The 2,4-D treatments reduced the stand of freshly-rooted forms utilized by pocket gophers for feed.

Herbicides affect insects directly, or indirectly, by killing the plants on which the insects feed. It has been reported that 2,4-D is toxic to bees as a result of drinking contaminated water trapped on treated plants. Possibly 2,4-D might have some effect on nectar which made it toxic to bees. Radioactive 2,4-D can be translocated to the nectar of some plants and may be detectable there for 2 or 3 days after treatment.[30]

Palmer-Jones[31] found no effect on bees that had been directly dusted with 2,4-D or had crawled through a 2,4-D dust in order to enter the hive. 2,4-D has been classed as a stomach/contact poison of low toxicity to bees.[32] Johansen[33] reported that 2,4-D and related compounds were not toxic to bees, except when formulated as the alkanolamine salt or the isopropyl ester. Other workers reported total mortality of bees within 4 days of feeding 20 mg.[34] Morton fed bees 2,4-D at 100 ppm in 60 percent sucrose and found a reduction in reproduction.[35] He feels the "no effect" level in this type exposure is about 50 ppm. There was no evidence of bees bringing 2,4-D back to the colony from sprayed plants. When only 2,4-D-contaminated water was available to bees, broad reproduction was eliminated, but was restored when good water was made available. Some bees were drowned in 2,4-D-treated water, but this was caused by the wetting action of the surfactant used with 2,4-D. The surfactant was not toxic per se.

C. Toxicity and Hazard of 2,4-D to Man

Despite the extensive use of 2,4-D for weed and brush control, poisoning by the material is not common in man. It is generally accepted that auxin-type herbicides, when correctly handled or used for weed control,[1/] do not present a direct toxicity harard to man.

The principal routes of entry to man are either orally or by inhalation. There appears to be little hazard of transport through the skin, although individual allergies can develop. Eyes may be directly, but usually temporarily, affected.

In 1945, Kraus reported that he had taken 0.5 g of 2,4-D per day for 21 days with no demonstrable ill effects.[36/] In 1951, Assouly experimentally consumed 500 mg of 2,4-D daily for 3 weeks with no apparent detrimental effects.[37/]

In 1959, Goldstein et al. reported three cases of peripheral neuropathy following exposure to an ester of 2,4-D.[38/] Monarca and DeVito, in 1961, described neurological symptoms, i.e., atoxia and reflex disorders, following the inhalation of a large amount of 2,4-D vapor. Symptoms persisted for 3 months, leaving no reported residual.[39/] In 1962, Todd described a patient with a peripheral neuritis lasting almost 2 years and attributed the condition to exposure to the same material. Berkley and Magee in 1965 reported a fifth case of neuropathy in a farmer after exposure to the dimethylamine salt of 2,4-D. All these cases involved skin exposure to the herbicide.

There appears to be only one documented fatal case of 2,4-D poisoning by the oral route.[40/] A 23-year old man committed suicide in 1965 by apparently drinking 125 ml of a 50 percent solution of 2,4-D dimethylamine salt. The weight of 2,4-D in the body was about 10 percent of the total weight of active material ingested (equivalent to 80 mg/kg). The principal damage appeared to be to nerve tissue and the central nervous system.

Recently, Berwick reported a case where a man accidentally ingested a commercial preparation of 2,4-D herbicide.[41/] The patient was a 49-year old white farmer. While operating his tractor in the hot sun, he became thirsty and swallowed a mouthful of concentrated weed killer (Knoxweed), believing that it was iced tea. Although the exact quantity is unknown, it was estimated that he ingested approximately 30 ml. It was calculated that the farmer consumed about 110 mg/kg of 2,4-D. He exhibited fibrillary twitching and paralysis of intercostal muscles, and there was evidence of generalized sketetal muscle damage as indicated by marked elevation of serum glutamic oxaloacetic transaminase, serum glutamic pyruvic transaminase, lactic dehydrogenase, aldolase, and creatine phosphokinase levels. Hemoglobinuria as well as myoglobinuria (previously unreported in this condition) was observed. The patient recovered, and 36 months later he did not show any signs or symptoms of peripheral neuropathy.

Since the amount of 2,4-D found in food crops has been insignificant, it would seem that there is little hazard to man from those sources. Williams was unable to detect any residues in a number of total-diet samples down to the limits of sensitivity (0.01) of his analytical techniques.[42] Duggan calculated chemical residues in total-diet samples collected on 46 days in 25 American cities over a 699-day period.[43] The samples represented a food and drink supply sufficient for 644 days. It was found that 2,4-D averaged about 0.003 mg/day, and that the compound was found in oils and fats (0.001 mg) and in sugars and sugar products (0.002 mg in 1965-66 and 0.004 mg in 1964-65).

D. Teratogenic Effects

During 1965-1968, Bionetics Research Laboratories carried out teratogenic studies with 2,4-D as well as other pesticides.[44] Using mice as test animals, a statistically significant increase in abnormal fetuses within litters was observed when 2,4-D isoctyl ester, 2,4-D butyl ester, and 2,4-D isopropyl ester was administered. The isopropyl ester of 2,4-D was statistically significant at the 0.01 level for one or more tests, while the isoctyl ester of 2,4-D was statistically in those factors only at the 0.05 level. An increase only in the proportion of abnormal litters of mice born during 1965 was observed following treatment with 2,4-D methyl ester; the statistical significance of the incidence was weak.[45]

Collins and Williams investigated the terotogenic effects of 2,4-D from three different manufacturers on hamsters. The incidence of fetal anomalies resulting from the administration of the three materials was quite low, and the incidence that occurred most frequently was the same anomaly that was observed in the control animals. Fused ribs were seen in nine of 11 reported anomalies among 132 live fetuses from dams fed 2,4-D. The three anomalies in the control group of 942 live fetuses were fused ribs. The lowest dose causing these effects, i.e., 60 mg/kg, would be approximately 600 ppm in the diet. The maximum human dietary exposure to 2,4-D from permitted tolerance is 0.3 ppm.

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X. ALTERNATE METHODS OF SAGEBRUSH CONTROL (OTHER THAN WITH HERBICIDES)

A. Introduction

Spraying with herbicides is presently the most widely used method of sagebrush control. However, other methods including both mechanical and nonmechanical techniques, have been employed. Generally, the equipment that is used was designed for other purposes. Examples of such equipment are the one-way disc (Wheatland type), the plow and off-set disc, the anchor chain or roadnipper, and brush cutter and beater (built for other types of brush). A few implements were designed especially for sagebrush control like the sagebrush rail, the pipe harrow, and brushland plow.

Of the many methods developed to kill sagebrush, no one technique is universally the best because the brush grows under widely varied conditions. The suitability of control measures varies with density, height, and age of the sagebrush stand; associated shrub species; amount of grass understory; topography; amount of rock on the area; type of soil and its susceptibility to erosion; facilities available for doing the work; size of the area to be treated; personal preference; and other related factors.[1/]

B. Selection of a Method of Sagebrush Control

Pechance et al.,[1/] recommended that the following eight points be considered in selecting a method of sagebrush control:

1. Employ a Method That Kills Most of the Sagebrush: A method that provides an extensive kill of sagebrush is highly desirable. A treatment that leaves fewer than three sagebrush plants per 100 square feet is considered successful, because the reestablishment of sagebrush then is very slow, and the seed sources have been greatly reduced.

2. Employ a Method That Also Kills Associated Undesirable Species: It is very desirable to eliminate other unwanted species of vegetation associated with sagebrush. After sagebrush has been eliminated from the area, other undesirable plants may then become established. Plants like rabbitbrush or horsebrush may increase following sagebrush elimination, and prevent improvement of the rangeland. Annuals like cheatgrass and halogeton also can populate a treated area, and interfere with the growth of seeded grasses.

Other species of plant may become prevalant in a treated area that has some usefulness as range forage, depending on the kinds of livestock or game using the range. Plants like broad-leaved herbs, perennial grasses, bitterbrush, and fourwing saltbrush, are usually considered as desirable vegetation.

3. Employ a Method That Does Little Damage to Perennial Grass Remnants and Other Desirable Plants if Artificial Seeding is not Necessary, but if Seeding is Planned, Use a Method That Kills Most of the Vegetation: In many range areas, enough grass is present that revegetation will occur following removal of sagebrush. If the remants of grass are destroyed by the treatment, seeding will be necessary and the cost of the treatment is nearly doubled. Seeding is sometimes uncertain, and stands of desirable grasses should be preserved if possible.

All vegetation should be killed if seeding is planned to improve forage quality. Seeding to supplement the desirable species in a treated area often has not been successful. Therefore, it usually is better to kill all plants and to prepare a good seedbed. New grass becomes established more easily, and competition from native vegetation is eliminated.

4. Employ a Method That Leaves the Land Suitable for Seeding, Where Seeding is Necessary: Sometimes the method of sagebrush removal leaves a barrier of dead woody material that makes the use of grain drills difficult. Additional operations often are necessary to remove the barrier before seeding can be carried out.

5. Use a Method That is Widely Applicable: Employ a treatment that kills the most sagebrush of different ages and various sizes, and that is effective on terrain varying in slope and stoniness. Such a method is more useful than a method applicable to restricted conditions.

6. Use a Method That Utilizes Readily Available Equipment Adapted to Other Uses: The acquisition of equipment designed specifically for sagebrush control generally is not practical. Only if a very large amount of control is carried out will the cost of such specialized equipment be justified. Sometimes it is feasible for a group of ranchers to purchase expensive items for use on a cooperative basis. The use of equipment that can be used for other purposes, and the contracting for sagebrush control by commercial operators, are the most common practices.

7. Use a Method That Will Not Increase Erosion Hazards: Some methods remove so much of the vegetation from an area that wind and water erosion become serious factors. In terrain where soils are light and subject to drifting, or on slopes, methods should be selected that will leave litter and plant material as a protective cover on the soil surface. Methods that help fill gullies and break down existing erosion patterns are desirable.

8. Choose a Method That is Economical but Also Satisfies Any of the Other Seven Points That May Apply to the Area to be Treated: An effective method that is reasonable in cost should be used. However, consideration also should be given to other factors as well. Methods should be employed that do not encourage erosion, and that produce the maximum range improvement, although these methods may not necessarily be the lowest in cost.

C. Methods

The most widely used non-chemical methods for control of sagebrush on rangelands include burning, plowing or disking, chaining, cutting and harrowing.[1] These methods are discussed in the following section.

1. Planned Burning: Burning has been used as a technique for sagebrush control for many years. The technique is inexpensive and widely adaptable; however, it must be used skillfully to insure range improvement. The range to be burned must be carefully selected, the time of burning is important, and precautions must be taken to control the fire or range detioration may result. Pechance et al. listed several advantages and limitations of planned burning for sagebrush control.[1]

a. The kill of sagebrush: Proper burning technique results in a complete kill of plants of different ages and sizes, of big and low sagebrush, and black sagebrush. Most threetip sagebrush is killed, but a small percentage of the bushes may sprout from the base. Silver sagebrush sprouts readily from the stem base and roots, and the kill is generally low.

b. Kill of associated undesirable vegetation: Rabbitbrush, horsebrush, snowberry, and other associated sprouting shrubs usually are not killed by burning. Late summer burning has been somewhat effective in controlling rubber rabbitbrush, and earlier midsummer burning has resulted in a much reduced stand of cheatgrass the following spring; burning in the late summer or early fall is less effective.

c. Effect on desirable forage plants: Burning results in little damage to most useful forage plants, and the vigor of principal perennial grasses the following year is not likely to be reduced more than 30-40 percent. Conversely, Idaho fescue and bitterbrush (at some locations) have been severely damaged by burning.

d. Ease of seeding after burning: Following burning, seeding is easily carried out except on rough and rocky sites or slopes over 30 percent. When land is too rocky or steep, seed can be covered by anchor chains or a heavy pipe harrow fairly successfully. Adequate seed cover is not provided by sagebrush ashes alone.

e. Adaptability to terrain and soil: Burning can be employed with a variety of soils under different conditions of steepness of slope and irregularity of terrain. However, it must be possible to construct a wide and safe fireline.

f. Effect on erosion hazard: Because debris and litter are mostly consumed by fire, the soil is seriously exposed to erosion. Generally, burning should not be used on steep slopes or on soils that easily blow or wash.

g. Cost of control: For tracts of 1,000 acres or more, cost of sagebrush control by planned burning is $1.00 to $4.00/ acre, on the basis of 1962 wages and equipment rental rates.1/ This sum includes up to $200.00 a year for constructing firelines, the direct cost of burning the area, and the cost of leasing additional range for 1 or 2 years to permit protection of the burned area.

h. General Adaptability of Planned burning for sagebrush control: Mueggler and Blaisdell2/ report that burning was the only treatment that injured any grasses. The *Carex filifolia* - *Festuca idahoesis* group was most severely reduced by burning. Other grasses, though set back temporarily, soon recovered. Grasses as a group were greatly favored by the other treatments in the study. Although burning brought about the greatest increase in total forbs, *Antennaria microphylla* and *Penstemon radicosus* were injured. *Astragolus*, *Eriogonum*, and *Lupinus* species were most benefited. Pechance, Stewart, and Blaisdell3/ state that (1) burning should not be done where the principal use of the area is a watershed, timber production, or important values other than grazing; (2) not where soils are highly susceptible to wind and water erosion; (3) not where important grasses, weeds, and browse are seriously damaged by fire; (4) not where more than half of the understory is cheatgrass brome, unless the area can be protected from accidental fires; and (5) not where there is an abundance of such sprouting shrubs as horsebrush and rabbitbrush.

Blaisdell[4/] in his summary and conclusions stated that fire has been widely used in sagebrush eradication, and that unrestricted burning followed by overgrazing has often resulted in serious range depletion. Several studies have indicated that planned burning can be a valuable tool in the improvement of sagebrush grass ranges. In his ecological study, he found that all grasses were injured by burning, but thickspike wheatgrass, plains reedgrass, and bluebunch wheatgrass recovered rapidly and made substantial increases within 3 years as compared to the same species on unburned control areas. Other grasses were slower to recover.

As with the grasses, forbs were injured to some degree by burning, but most of the rhizomatous species recovered rapidly and within 3 years were producing more herbage on burned than on unburned range. Yield of suffrutescent species was greatly reduced initially, but none of the perennial forbs were permanently damaged, and many apparently benefited from the reduced competition as shown by significantly higher forb herbage on the burns.

Shrubs were apparently more damaged by burning than grass or forbs, but rubberbrush and horsebrush sprouted profusely and quickly regained or surpassed original size. Substantial numbers of bitterbrush plants also sprouted, and these were quickly able to gain a position of dominance. Sagebrush, which must start entirely from seed, was greatly handicapped.

The amount of forage, which is affected by both availability and palatability of the herbage, was markedly greater on the burned than on the unburned ranges. The estimated grazing capacity of the burned range was 40 percent greater than that on the unburned.

Organic matter, nitrogen, and moisture equivalent were significantly reduced in the top half inch of soil on the heavily burned areas, but these reductions were only temporary. Accelerated wind erosion was marked on the heavily burned areas that was effectively arrested within 2 years.

From the results of Blaisdell's ecological study, the following conclusions were drawn with respect to planned burning of sagebrush grass range.

1. Such burning is ultimately beneficial to shrubs with a strong sprouting habit and to hirzomatous grasses and forbs, but non-sprouting shrubs, suffrutescent forbs, and some of the finer bunchgrasses are severely injured. Other species are only slightly affected.

2. Because of this variation in response, composition of the stands should be carefully considered when planning a sagebrush burning operation. A large number of undesirable sprouting shrubs or of desirable fine bunchgrass or forbs may preclude improvement by burning.

3. Although total yield of grasses and forbs is greatly increased within 2 or 3 years after burning in comparison with production on unburned ranges, much of this early increase may be short-lived.

4. Increased availability of herbage and ease in handling livestock are often the main benefits from planned burning.

5. Some soil properties are highly altered by burns of heavy intensity, but such changes are only temporary.

6. The best results are apparently produced by light burns, but the advantages of a low intensity fire must be sacrificed in order to secure a satisfactory coverage.

7. Normally sagebrush reestablishment following planned burning is a gradual process, but sometimes sagebrush seedings become established the following year on the burned areas regardless of the amount of grass present before burning or management after burning.

8. The goal of sagebrush burning should be consistent with the climax cover that can be obtained.

In summary: after considering the information presented in the studies conducted with the use of fire for the control of sagebrush, one would conclude that burning is one of the cheapest methods available to remove sagebrush on densely infested sagebrush lands. However, there are some serious disadvantages to burning--the necessity for deferred grazing to enable the grass species that are injured to recover and invade the burned areas; proper management of livestock on the areas; the potential of the escape of the fire to areas not intended to be burned; and the potential of wind and water erosion.

2. Plowing or Discing: Despite the improvement in herbicides, plowing and discing continue to be the most valuable methods of sagebrush clearing where seeding is to be done, especially by drilling. Plowing or discing, correctly done, will kill 70-90 percent of all except silver sagebrush. The bigger the sagebrush and the softer the ground, the better the kill. Associated sprouting species, such as rabbitbrush, are not killed unless the discs cut much deeper than the customary 3-4 in. When this is necessary, the cost of the control is doubled. Cheatgrass and other undesirable annuals generally are effectively thinned if the work is done in the spring after seed germination but well before ripening; control will be ineffective if work is done after seed starts to ripen. Nearly all perennial

plants except those that spread by rootstocks or sprout from roots are killed by plowing or discing at a depth adequate for effective control of sagebrush. These methods should be limited, therefore, to ranges that are to be seeded. The average cost for plowing or discing under ordinary conditions based on 1962 wages and rates for equipment rental, range from $4.00 to $7.00/acre[1]

3. Anchor Chaining: Anchor chaining, a common method of controlling juniper and pinyon in the West, has proved to be a rapid, low cost method for reducing competition of big sagebrush. It provides only partial control, but costs less than other methods. It is especially useful where a mere thinning of the brush stands is desired and for removal of juniper and pinyon trees as well.

Chains weighing from 25 to 90 lb/link have been used. Chains with links heavier than 70 lb eliminate more sagebrush than lighter chains. Twice over is usually desirable. A second chaining not only removes additional brush, but also facilitates seeding operations by covering seed broadcast between the 2 chainings or by breaking down the brush to any subsequent drilling.

4. Cutting, Beating, or Shredding: In recent years the cutter, beater, or shredder type of implement has been widely used in sagebrush control. These machines cut and shred the woody and herbaceous-type growth. They leave a coarse litter layer on the soil surface.

Cutting is effective in tall old stands of big sagebrush; kills of 90 percent or more of old sagebrush are often obtained. Young plants of big sagebrush are usually missed or little damaged by cutters and flails. Control of threetip, low, and black sagebrush is only partially satisfactory because of their low, spreading branches and the tendency of threetip sagebrush to sprout from the base.

Grasses and broadleafed herbs growing beneath the sagebrush are not damaged. Bitterbrush is badly damaged, but in some localities it is stimulated into bigger sprouting from the root crown.

Cutters should not ordinarily be used on soils where rocks protrude more than 3 inches above the soil surface. Maintenance and repair costs are high if the blades or flails come in frequent contact with rocks. Moreover, cutters must be operated carefully where the soil surface is uneven or is cut up by small gullies.

The woody plant material left as a protective mulch on the soil surface should decrease the erosion hazard. Thus, cutting is a good method of sagebrush control where the probability of wind and water erosion is fairly high and watershed values must be guarded.

5. Harrowing: Self-clearing pipe or log harrows, sometimes called Dixie drags, have occasionally been used for sagebrush control, but are most useful for covering grass seed on burned rangelands that are too rocky or rough for use of other type of implements. They have been used to cover seed on woody alpine areas and to control rather open spans of old, brittle sagebrush on uneven ground, especially on ranges with numerous rock outcrops.

Only 30-70 percent of old, brittle sagebrush and a much lower percentage of younger plants are killed.

About 10-20 percent of the bunchgrasses will be uprooted by the pipe harrow. Damage to bitterbrush is low unless it is tall and brittle. Few plants are killed.

Harrowing usually decreases erosion. Litter and debris from uprooted and broken sagebrush left on the loosened ground surface and deposited in gullies, along with the standing brush protects the soil better than standing brush on untreated areas.

Harrowing and plowing, on sites to which they are adapted, should cover about the same number of acres/hour at similar costs. Computed at 1962 rates, the cost would be $4.00 to $7.00/acre, or about the same as for plowing.

6. Other Methods: Many other methods have been tried in clearing sagebrush for farming or range improvement. They include rooting or dragging, root cutters, mowing, ripping, rolling brush cutter, road graders or bulidozers, and flooding. Any one of these methods may be useful for sagebrush control, especially if equipment is readily available. All these methods, the limitations and potentials are discussed in Pechance et al., Bulletin No. 277. Kearl and Brannon[5/] studied the economics of rotobeating, railing, disc plowing, scraping with patrol or grading and moldboard plowing. They presented the cost/acre for brush removal alone as $2.43 for the disc plow method, $4.76 for rotobeating, $6.07 for railing, $6.61 for patrol or grader, and $13.61 for moldboard plowing. Additional costs for seeding brought total costs for brush removal and seeding to $6.15 for disc-plow method, $8.94 for rotary beater method, $9.91 for the patrol or grader method, and $18.45 for moldboard plow method. Patrol or scraping, disc plowing, moldboard plowing noble blading and flail scrape plowing all gave fair to excellent results in controlling big sagebrush. Scrapping with a patrol all gave results varying from fair to excellent in controlling silver sagebrush, rabbitbrush and pricklypear cactus. The other methods, which gave good to excellent results on big sagebrush, gave only poor results on other brush species.

Railing and rotary beating attempt to break off or uproot brush. They produce poor to fair results when compared with other mechanical methods or with chemical control. Railing in several instances actually increased the number of other brush species observed.

Herbage production was consistent with control affecting this data in that methods which were effective in controlling sagebrush and which were then followed by reseeding also produced good increases in herbage. Railing and rotary beating also increased herbage production, but the increases were not as large as they were for methods where seeding was feasible, and was used.

An economic evaluation of this practice was made by projecting the useful life of the method upon conditions observed on the improvement sites and results reported in literature at setting costs that the average level determined. Forage values of $5.56/AUM are required to cover variable costs, and $7.48/AUM is required to cover total cost from using the railing method. Forage values of $3.79/AUM and $5.74/AUM are required to cover the variable costs or variable-fixed costs for the patrol or grader method without reseeding.

These are exorbitant values/AUM, and it is doubtful that either railing or the patrol method without reseeding is a feasible method of brush control.

Using the rotary beater method would require a value of about $1.49 per additional AUM to recover variable costs and $2.68 per additional AUM to recover variable-fixed costs. Other methods, the patrol or disc plow followed by seeding, or chemical control, would require values per AUM of less than $1.00 up to slightly less than $2.00, depending upon the method chosed and the extent of ASCS participation.

The railing and patrol or grader method without reseeding would not produce enough returns to recover investment costs at any interest rate. The rotary beater method would return about 20 percent on variable costs and 4 1/2 percent on total cost. By contrast, chemical eradication with ASC assistance would return about 26.5 percent on total costs over the life of the improvement practice if ASC assistance were received. This method would yield about 10.5 percent on total cost without ASC assistance. The patrol and disc plow methods with seeding would return about 17 and 20 percent on variable costs and 14 and 18 percent on total cost.

Chemical control is the ideal method where terrain and topography prohibit use of the patrol or disc plow followed by reseeding. Chemicals can also be applied rapidly to large acreages. Hence, it is also an ideal method to be used where very large acreages of brush are available for treatment.

The relatively high costs of mechanical methods, including costs for fencing and range deferment to establish a grass stand, can be prohibitive on large acreages, even where physical conditions are suited to mechanical methods. Total capital requirement for mechanical methods with reseeding and the requirement for deferment of large acreages introduce serious management and financial problems. Chemical control can be used without encountering these types of problems.

Mechanical methods, even the patrol or the disc plow method, followed by reseeding, are desirable (1) where preexisting fences control grazing adequately and permit establishment of grasses, without large additional costs for fencing; (2) where topographic, soil and moisture conditions permit good establishment of grass stands; (3) where smaller areas of sagebrush are available for the control work and (4) where the operator desires maximum returns per acre rather than the maximum rate of return on capital investment.

Finally, Kearl states that mechanical methods with reseeding can be recommended even on relatively large tracts if (1) the ranch operator has sufficient capital to accomplish all that is desired, (2) has sufficient land so he can defer relatively large tracts without incurring serious management or financial problems. Application of a range improvement practice to large tracts and costs of application to large tracts may vary considerably because of fencing requirements.

Kearl and Brannon also sampled several of the sites where the sagebrush had been controlled by the various mechanical methods and report for the herbage production on the various mechanical sites as grading with no reseeding a 152 percent increase in herbage production; rotary beater--no seeding, 133 percent increase; patrol with no seeding--77 percent increase; a patrol with seeding--241 percent increase; disc plow-seeding--369 percent; a moldboard plow and seeding--958 percent; flail-scrape-plow with seeding--226 percent increase; noble blade, no seeding--504 percent increase in herbage production.

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XI. APPLICABLE LAWS AND REGULATIONS GOVERNING PESTICIDE USE

Federal and state laws and regulations concerning the use and sale of pesticides within the study area are discussed in this section of the report. Litigation relating to the use of herbicides, effects of herbicide laws on the environment, and changes in laws recommended for adequate environment protection also are included.

The material in this part of the report was prepared by Dr. Norman G. P. Krausz, Professor of Agricultural Law, University of Illinois, Urbana, Illinois.

A. Federal Laws and Regulations Relating to the Sale and Use of Herbicides on Rangeland Sagebrush

Federal laws relating to pesticides are of two kinds. One is direct such as the Pesticides Registration Law[1] and the Food Law[2] that requires pesticide tolerances for residues on foods. The other kind is less directly applicable and includes the recent rash of laws for the control of air and water pollution and setting policy for an environmental quality program.

Pesticide Laws. Federal pesticide laws apply only to commodities shipped in interstate commerce. However, the interstate commerce clause has been broadly defined and few transactions escape federal jurisdiction. Also, state regulations are patterned after federal law and often prescribe the same tolerances.

A Federal Insecticide Act was passed in 1910 covering the marketing of insecticides and fungicides. It was designed mainly to protect the farmer from substandard and fraudulent products. In 1947, the Federal Insecticide, Fungicide and Rodenticide Act superseded the older act and extended coverage to herbicides and rodenticides. This law requires pesticide products to be registered with the EPA. Application for registration must be accompanied by the manufacturer's statement of composition (chemical analysis), the names of the pest or crops on which the product is to be used, and the specific conditions under which it is to be used. Registration may be granted if the substance does not constitute a public health hazard or cause (serious) injury to the environment.

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[1] Federal Insecticide, Fungicide and Rodenticide Act, USCA 7-135.

[2] Food, Drug and Cosmetic Act, USCA 21-346.

In 1959, an amendment to the 1947 Act extended coverage to nematocides, plant regulators, defoliants and desiccants. Another amendment in 1964 eliminated the controversial "registration under protest" provision of the 1947 Act, and authorized the Secretary of Agriculture to require pesticide labels to bear the federal registration number (some states also have this requirement now). Regulations were revised in 1964 to require "signal words" (danger, caution, warning, etc.) and "Keep Out of the Reach of Children" to appear on the front panel of all poisonous pesticides.

The Food, Drug and Cosmetic Act (1938) provided that tolerances be established for pesticide residues in foods where these materials were necessary for the production of a food supply. The Miller Amendment (Public Law 518) passed in 1954 provides that any raw agricultural commodity be condemned as adulterated if it contains any pesticide in excessive amounts and whose safety has not been formally cleared. It also gives the Secretary of Health, Education and Welfare the power to establish such residue tolerances.

The two basic federal statutes, the Insecticide, Fungicide and Rodenticide Act and the Miller Amendment to the Food, Drug and Cosmetic Act,supplement each other and are interrelated by law and practical operation.

Registrations of pesticides may be cancelled at the end of 5-year periods but renewals can be granted on request. If there is an imminent hazard to the public, an economic poison registration can be suspended immediately and may be seized if such action is deemed necessary. Cancellation may follow if the requirements of the law or regulations have not been followed.

Persons adversely affected may, within 30 days, request a public hearing. A final order of the Agency may be appealed to the U.S. courts.

Violations of the law or the regulations of EPA are a misdemeanor with fines ranging to $500 for the first offense and to $1,000, plus possible imprisonment up to 3 years, for subsequent offenses.

Both law and detailed regulations exist for the application of herbicides to federal lands. A Noxious Plant Control Law[1/] also allows states to enter federal lands to destroy weeds if the plan is approved by the federal agency in charge. States may be reimbursed for their costs if federal funds are available for this purpose.

[1/] P.L. 90-583 (1968), 82 Stat. 1146.

The Bureau of Land Management, Department of Interior, is guided by Interior Memo 71-228 in applying herbicides to sagebrush. This Memo was issued 22 June 1971, and is replete with provisions to assure that the environment will not be damaged.

For example:

1. "The Department will use all means to reduce pollution resulting from pesticide use.

2. "No pesticide will be used when...water will be degraded, or hazards exist that will unnecessarily threaten fish, wildlife, their food chain, or other components of the natural environment.

3. "Examine all alternatives and consider impact each will have on the ecosystem and the total environment."

The Interior Department states that a working group on pesticides, comprised of representatives from different agencies (about 30) serves as a coordinating mechanism for the use of pesticides in the federal government. The group reports to the Council on Environmental Quality and makes recommendations to all federal agencies using pesticides.

The Bureau of Land Management, State Director for Montana, replied by letter that "In Montana, we have an agreement with the Fish and Game Department. They are notified well in advance of treatment projects (two or more years) and make recommendations relative to protection of big game and upland bird habitat. Normally, we have already blocked out known areas of winter use and areas adjacent to water. We have always tried to leave 50- to 100-ft buffer strips along streams--not only for habitat protection but to prevent stream contamination.

"We will also, this coming year prepare environmental analyses on sagebrush control jobs, as required of the National Environmental Policy Act.

"Because of increasing questions regarding the entire sagebrush control field and its impact, particularly upon habitat, plus our economic considerations, we have been decreasing our program in Montana over the last few years. In 1972, we will probably treat less than 3,000 acres of public land in the state.

"Answering your last question regarding our recognition of state laws and regulations is difficult. To our knowledge, federal restraints, through secretarial order and internal direction, as well as through the NEPA are far more restrictive than are Montana laws and regulations. Our working agreement allowing State Fish and Game Department review and recommendation is based upon their particular knowledge and expertise relating to wildlife habitat which sagebrush control might affect."

Environmental Quality Laws. One can no longer use pesticides without being concerned with the possibility of pollution. Pesticides become pollutants when they or their degradation products remain in the environment after desired purpose has been accomplished. Increased public concern over the long-range effects of pesticide residues in humans and animals has caused an increasing amount of state and federal legislation in this area.

Federal laws in the area of pollution have focused mainly on interstate and navigable waters. Basic legislation applicable is the Federal Water Pollution Control Act[1/] which gave the Secretary of the Interior the power to bring abatement action against those guilty of polluting interstate waters. The Water Quality Act of 1965[2/] provides that states must have minimum pollution standards for interstate waters. The Water Quality Improvement Act of 1970[3/] continues to encourage states to act by providing grants-in-aid for improvements and funds for a research program. The primary rights and responsibilities of the states are to be protected and aided, but when they fail to act, EPA has the authority to enforce water quality standards.

An old law, passed by the Congress in 1899 and referred to as the Refuse Act,[4/] has been used to prosecute individual polluters. It contains the famous (or infamous) squealer clause allowing one-half of the fine to be paid to the person furnishing information leading to the conviction.

Other federal laws provide for federal aid to projects in abatement of pollution. The Water Resources Planning Act[5/] encourages development and conservation of water resources with particular emphasis on cooperation between the various levels of government. The Rural Area Water Facilities Act[6/] provides federal money for use in solving water and waste disposals in rural areas. For the purposes of this act, a rural area, as defined, does not include any area in which there are cities or towns of more than 5,500 population.

[1/] 33 USC 466.
[2/] P.L. 89-234.
[3/] P.L. 91-224.
[4/] USC 33-412.
[5/] P.L. 89-80.
[6/] P.L. 89-240.

Closely related to the water pollution laws are the National Environmental Quality Laws.[1] The policy is to prevent or eliminate damage to the environment and establish federal administrative offices for control, financial and technical assistance to the states and local governments, and requires the cooperation of all federal agencies.

A Council on Environmental Quality is established to advise the Congress and the President on the condition of the environment and make recommendations for improvements. An Office of Environmental Quality is established to staff the council and assist federal agencies in appraising their programs and establishing standards.

One special law on agriculture should be mentioned that relates to land conservation and pollution.[2] The Secretary of Agriculture may enter into long-term soil conservation contracts with farmers and ranchers for the prevention of soil erosion and for water conservation, with special authority in the Great Plains area. Measures include the objective of controlling agricultural pollution from erosion. A special appropriation is made for cost sharing for conservation practices in specified Great Plains states.

B. State Laws and Regulations on the Sale and Use of Herbicides on Rangeland Sagebrush

It becomes readily apparent that many state pesticide laws are of recent vintage, usually dated within the last few years. Exceptions are noxious weed laws and some of the "Economic Poisons Acts" that were patterned after federal law requiring registration of pesticides. In years past if registration was granted by USDA, usually little trouble was encountered from the states. Recent amendments to some of the state laws have tightened registration requirements considerably, particularly when highly toxic pesticides are involved or when there may be serious damage to the environment.

The following contains a summary of the various pesticide and related laws in the states under study.

1/ National Environmental Policy Act, USCA 42-4321 (1969); Executive Order No. 11507 (4 February 1970); Environmental Quality Improvement Act, USCA 42-4371 (1970).

2/ USCA 16-590p.

Colorado.[1] An early weed control law in Colorado placed authority in the County Board. The Board can employ a Weed Superintendant and supply him with equipment, materials and money for the control of noxious, injurious and poisonous weeds that cause damage or loss to land or livestock. A special weed tax levy can be imposed to replenish county funds used for weed extermination.

In 1965, a Pesticides Act was passed requiring registration. Jurisdiction was placed in the Department of Agriculture as has been the common practice in most other states. Authority is broad when compared to similar laws in other states--"The Department may restrict or limit the manufacture, delivery, distribution, sale or use of pesticides that are highly toxic to man...and may issue stop sale, use or removal orders... and institute criminal proceedings."

The 1965 law has been refined further by a new law, effective 1 January 1972. A class of "restricted use pesticides" is established which the Department determines may create an undue hazard to persons, animals, wildlife or land. The list is to be adopted after hearings are held and regulations on this class may be issued to control time and conditions of sale, distribution, and may require use by permit only. An advisory committee of 13 persons is to be appointed by the State Agricultural Commission to provide assistance in formulating regulations. USDA regulations can be adopted in the interest of uniformity. As in the old law, the Department of Agriculture may issue a stop sale, use or removal order if there is reasonable cause to believe there is a violation. If criminal action is contemplated, the facts are referred to the district attorney. The new law also requires an annual license for pesticide dealers with no qualifications specified.

Another law, also common to many other states in the nation, enables pest control districts to be established by petition to the County Board. Infested areas may be sprayed and a reluctant minority charged their share of the expense.

In 1966, Water Pollution and Air Pollution Control laws were passed, both to be administered by the Public Health Department. However, a Water Pollution Commission was given final authority in water pollution prevention and control administration. Remedies are through the injunctive process and damages for loss of fish. In 1968, the Commission was given more continuity by appointing the Executive Director of the Department of Natural Resources as permanent chairman.

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[1] Colorado Statutes--Article 5, S. 6-1-4; S. 6-9-2; Article 12, S. 66-28-1.

A law on the use of agricultural chemicals was passed in 1967, and amended in 1970. Commercial applicators must be licensed and carry liability insurance up to $50,000 or show sufficient financial responsibility. Some of the usual prohibitions are present in the law. For example, it is unlawful to:

1. Apply pesticides carelessly.

2. Create a hazard from storage or use to humans, animals or fish.

3. Dispose of empty containers so as to create a hazard.

The Commissioner of Agriculture has authority to prescribe the materials to be used and the method of usage, which is unique in many of these kinds of laws.

Idaho.[1] The application of pesticides has been regulated in Idaho back to 1953, but the scope of the law has been broadened by amendments in 1961 and 1967. The present law requires licensing of commercial pesticide applicators and they are subject to regulations by the Commissioner of Agriculture in the interest of public health. Further, the Commissioner can define areas or zones for specific restrictions on the use of herbicides, such as 2,4-D, when he determines they would injure animals or crops. He may, in fact, prohibit the use of these types of chemicals in such areas.

The old Economic Poisons Law (1963) is now addressed as the Pesticides Law. Amendments have been frequent and it now is a comprehensive law covering registration of pesticides, labeling, adulteration, enforcement and licensing of dealers. Registration of pesticides and licensing of dealers is yearly, but the fee of $10 is minimum. The range for most states is from $10 to $25 for each registration.

Authority to investigate the composition, uses and effects of pesticides seems quite adequate and a possible fine up to $1,000 and imprisonment up to 1 year may be sufficient to obtain compliance. However, enforcement is delegated to county prosecuting attorneys and it appears they may act at their option.

A new law in Idaho (1970) addresses itself to the eradication of weeds. Primary responsibility is placed on the property owner but the law outlines a procedure for having the Commissioner of Agriculture assume control in certain cases. The law makes no mention of pesticides or their regulation in destroying weeds. Presumably the Pesticides Law and regulations would then apply.

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[1] Idaho Statutes, Title 22, Ch. 24, ss. 22-2208-2230; Ch. 24, ss. 22-2441-2462; Ch. 34, ss. 3401-3412; Ch. 42, s. 10; Ch. 120, s. 1; Ch. 240, s. 1.

Montana.[1] Montana has an updated Weed Control Law. It still is oriented toward named noxious weeds such as Canada thistle, but the law allows the county commissioners to define any weed as noxious.

A 1969 amendment requires a weed control district for each county which is to be administered by three supervisors. They can institute control measures and send the bill for expenses incurred to the land owner. A weed fund produced from a general or special tax levy allows a positive program. The funds can be used to pay part of the land owner's cost of weed control.

Montana took two long strides in favor of the environment in 1971. First, the Water Pollution Law was severely amended by placing administration in the Department of Public Health with a Director of Water Pollution Control, by broadening the definition of pollution to include almost any kind of contamination, and by adding to the Pollution Advisory Council a livestock feeder, a labor representative, a supervisor of a soil and water district, and representatives from water recreational enterprises.

The second action relates to a completely new Pesticides Act effective 1 January 1972. It is the most complete law surveyed out of the six states studied for this project. Because this seems to be the "ultimate" in current legislative drafting, a more complete summary follows:

1. It is administered by Department of Agriculture.

2. Label must contain a warning or caution to prevent injury to man or undue hazard to the environment.

3. All pesticides for sale in the state must be registered annually. The fee is $10. The Department must review all registered pesticides every 2 years.

4. Pesticides registered under federal law are entitled to state registration but the state may impose restrictions on the type of applicator and on the time and place of application.

5. The Departments of Health and Fish and Game also must pass on each registration. Two votes are needed (including Agriculture) for approval. If less than two departments approve, the applicant may ask for a joint administrative hearing and then a special advisory committee has approval power.

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[1] Montana Statutes, s. 16-1701-5; s. 69-3901; H. B. 85(1971) S. B. 126 (1971).

6. The Department has broad powers to inspect, sample and embargo pesticides, but must obtain approval of a district court to condemn the pesticide.

7. Commercial applicators must be licensed by the Department--annual fee of $10. Additional fees may be imposed by regulation for the purpose of controlling operators. Also proof of financial responsibility is required.

8. Dealers selling pesticides must also be licensed--fee of $10. Both applicators and dealers must pass an examination. Sales for home, garden, yard and lawn may be made without restriction except for limits on quantity.

9. Farm applicators must obtain an annual special use permit. Each applicant must take a written examination on the use and application of restricted pesticides and justify his use on crops, land or livestock.

But farmers need not obtain a license for nonrestricted pesticides for their own property or for noncommercial operation on lands of neighbors.

10. Licenses and permits may be revoked for a variety of reasons including operating in a negligent manner. Decisions can be appealed.

11. All governmental agencies are subject to the Act.

12. Persons damaged by pesticide applications are to file a report of the loss to the Department within 30 days.

13. Hearings are required before regulations are adopted except for federal regulations under the IFR Act which may be adopted without hearing. Licensees are entitled to notice of such hearings.

14. The state may limit application during certain times to prevent damage to persons, environment, etc.

15. In an emergency, regulations may be issued for a period no longer than 60 days.

16. Hearings are also held on complaints that the law is being violated. Appeal is to the Commissioner of Agriculture and then to the courts.

17. Department is required to cooperate in developing and conducting educational programs on pesticides.

18. It is unlawful to discard pesticide containers so as to injure people or animals or wildlife or pollute any waterway.

19. Violation of the Act is a misdemeanor.

20. The Department may ask for court injunctions to stop violations.

The only comment one might make about this new law is that the penalty and enforcement provisions may have to be tougher some day. Using the judicial system for conviction on misdemeanor or for an injunction would, in some states, be painfully slow and the penalty inadequate.

Nevada.[1] Nevada recognized water pollution and chemical application problems earlier than most states. In 1917, a general water control law was passed making it unlawful to deposit poisonous substances (including chemicals) in the waters of the state. The Health Department apparently was the official water pollution agency.

The state became concerned about air pollution in 1967 and specifically named the Health Department as the control agency. Also established at that time was a Control Advisory Council. The Council serves in a consultive capacity on proposed air control regulations. It is interesting to note that counties also have authority to adopt regulations on air contaminants to control air pollution.

Another early law (1929) was the one on noxious weeds. As usual, responsibility is placed on owners and occupants to control injurious and noxious weeds, but a state Quarantine Officer has considerable power to direct County Boards to take action if owners or occupants fail to destroy such weeds. An unusual provision forbids naming a weed injurious or noxious if it is so well established in the state as to make its control or eradication impracticable.

In 1969, Weed Control Districts were authorized. A petition signed by 60% of the owners, who own at least 50% of the assessed value, must be presented to the County Board. Once established, the Board of Directors has substantial powers to control weeds and place liens on property if the cost is not paid.

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[1] Nevada Statutes, Sections 445.010; 445.445; 445.465; 555.130; 555.280; 586.010; Reg. 55.30-38; 86.01-18.

Restraints on using pesticides for weed control were placed in effect in 1955 by the Economic Poisons Law and the Custom Applicators Law. The Economic Poisons Law is now the Pesticide Control Act with 12 important sections added in 1971. The additions set out a class of "restricted use pesticides" which are injurious to man, animals or crops or detrimental to vegetation, wildlife or to the public health.

These amendments have a heavy emphasis on protecting the environment and on searching for alternatives when balancing the public benefit of certain pesticides against damage to the environment. Determining that benefits outweigh damages is one of the criteria listed in the law which the Director of Agriculture must use in deciding if a pesticide should be restricted. A restricted use generally requires a special use permit for each application.

The administrative procedure for enforcement is similar to other state laws of this kind--a notice of alleged violation is followed by an opportunity for hearing followed by referring the case to the local district attorney for prosecution if the violation is serious and uncorrected.

The Pesticide Applicators law requires annual licensing ($25) and liability insurance ($10,000 minimum). It is the regulations of the Department that tighten up the law considerably. Applicants are divided into principal, agent and operator. Licenses issued are classed as general, limited, restricted and special. Written and oral examinations are prescribed. Operational directions are comprehensive. Advance notice is required to persons that may be in the area or have livestock therein that may be harmed by the pesticide.

This thorough set of regulations contains much to be considered by other state Directors of Agriculture.

Oregon.[1] Oregon passed its Pesticide Registration Law in 1965. It contains the usual provisions on labeling, adulteration, misbranding, and registration. The original law contained sale and use restrictions if the pesticide was highly toxic to man. Protection has been extended to animals by recent amendments. The Registration Law is administered by the State Department of Agriculture.

The Department also administers a well drafted Pesticide Application Law. Licensees are classed as applicators, operators and trainees. Governmental units are exempt from licensing. A written examination is required of applicants on pesticide characteristics, application practices and techniques, laws, regulations and the protection of property. Short courses on these subjects are encouraged in cooperation with the state university. Financial responsibility is required. Insurance in an amount of at least $25,000 fulfills the requirement.

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[1] Oregon Statutes, Sections 634.215; 573.006; 573.380.

The Department can issue regulations classifying pesticides and methods of application for each class, but it is not clear how far the Director can go in forbidding the use of certain pesticides. Permits can be required for the use of certain esters. A permit is necessary for isopropyl ester of 2,4-D or any other ester of equal or higher volatility regarding plant damage. Permits are issued upon concurrence of the State Forester, the Director of Agriculture and a research specialist appointed by the President of Oregon State University.

An unusual part of this law is a mandate for a herbicide research program in cooperation with Oregon State University. This program was financed, at least in part, by a fee of 1¢ for each pound of herbicide parent acid equivalent, whose principal active constituent is derived from 2,4-D or 2,4,5-T, sold from 1961 to 1968. It is not known whether this fee is still imposed today.

Provision is made for protected areas in which a committee has authority to issue regulations on pesticide application. Any 25 landowners or owners of 70% of the acres, can petition the Department of Agriculture for a protected area. Following a hearing process, the Director decides whether special protection is needed in that particular area. A positive decision is followed by a referendum. The committee can levy a tax for administrative costs.

Wyoming.[1] The Wyoming Economic Poisons Law, passed in 1943, makes it unlawful for any person to manufacture or sell any economic poison within Wyoming which is misbranded or adulterated. Adulterated economic poisons include those intended for use on vegetation if the products contain substances that are injurious to other vegetation. The statute requires annual registration with the Commissioner of Agriculture of all economic poisons. The maximum penalty for failure to comply with the Act is $100.

Wyoming provides for the formation of Weed and Pest Control Districts of not less than 24 square miles. A petition from a majority of the landowners is submitted to the County Board. The Board has authority to create the District. The Boards of these districts are charged with distributing information concerning the control of weeds and pests, and with regular inspections for weeds. Boards are empowered to perform weed eradication services at the expense of landowners who refuse to control them themselves. The law provides for a lien to be placed upon the land of any person who refuses to pay after the Board has done the work for him. It also provides a maximum penalty of $100 for failure to comply with the Act.

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[1] Wyoming Statutes, Sections 11-55.1; 35.254; 35-487.

There is no law in Wyoming controlling the use of pesticides. Bills were introduced in the last legislature to impose licensing but they failed to pass.

The state did pass an Air Quality Act in 1967, to include "dust, fumes, mist, smoke, other particulate matter, vapor, gas, or any combination of the foregoing." Herbicides probably fall within this definition but a search of the law and cases did not product an answer.

To assist the Health Department with air pollution problems, an Air Resources Council was established. Its responsibilities are to develop programs to prevent air pollution, set standards, make investigations, and generally to carry out the Air Quality Act.

C. Litigation Relating to the Use of Herbicides

The older laws, such as the Economic Poisons Acts and the Noxious Weed Laws, have long been tested and found valid as a proper exercise of the police power of the states, and in the best interest of the general welfare, safety and health of the people. Newer laws, regulating the sale and use of pesticides, apparently are being accepted as merely an extension and tightening of previous legislation. No one seems to question the obvious need for some regulation of dangerous chemicals. A check of higher court decisions in the states under study brought no discovery of recent litigation relating to laws on the sale or use of pesticides.

However, an interesting federal case on registration of pesticides discussed the question of whether a nonapplicant for registration has a right to be a party in court. The Federal Circuit Court of Appeals for the District of Columbia decided that "organizations concerned with environmental protection have legal standing to challenge the government's decision to register or limit the use of a pesticide if they allege sufficient injury to man and other living things to create a controversy."1/ With the present concern about the environment, this seems like a reasonable position to take.

1/ Environmental Defense Fund, Inc., vs. Hardin, C.A.D.C., 428 F2d 1093 (1970).

The area of personal liability arising from pesticide application has resulted in many lawsuits. The majority view of the courts across the country is that the one applying the pesticide and also the farmer on whose land it is being applied are liable for damages caused if the application is done negligently. The basic theory is that a landowner must use his land in a reasonable manner with due regard for the rights and interests of others. If he negligently permits a dangerous substance to pass from his land to that of another he can be liable for any damages which result.

Most courts require a showing of negligence before holding a person liable for injury to adjoining owners or their property. Negligence is defined as the failure to use reasonable care under the circumstances. It might result from improper selection, mixing or application of chemicals.

A court could find negligence, for example, where spraying was conducted on a windy day, where the spray was applied too close to a fence line, where a pilot failed to cut off his spray over adjoining property, or where sprayer heads were not adjusted properly. However, once it is established that the damage was caused by his spraying, very little in the way of careless conduct is necessary to sustain a finding of negligence against a grower.

A minority of state courts recognizes that even the most careful applicator often can neither predict nor control the many elements that cause dusts and sprays to drift. These states dispensed with the negligence requirement and apply the doctrine of strict liability to crop spraying. Strict liability means that a person who makes use of an unusually dangerous substance does so at his own risk. In the words of one court:

> "The use by the applicator of a poison on his land which if it escaped, would cause injury to another was done at his own risk. He is responsible for its drifting and any precautions taken do not serve to distinguish his liability. The only question is whether his activities were the cause of the plaintiff's damages."

There is a question as to whether the grower can avoid liability by hiring the work done by a custom operator. As a rule, one who hires an independent contractor will not be liable for damages caused by the contractor's negligence. There is an exception to this rule, however, where the work to be performed is inherently dangerous.

Most state courts hold that crop spraying, both ground and serial, is sufficiently dangerous to impose liability upon the grower as well as on the custom operator--even though damage was caused by the custom operator.

Following is a brief explanation of the leading cases on liability:

1. Liability due to negligent application.

a. Failing to shut off spray in turning--Hammond Ranch Corporation vs. Dodson, 199 Ark. 846, 136 SW2d 484 (1940).

b. Spraying while winds were blowing toward neighbor's land--W. B. Bynum Cooperage Company vs. Coulter, 244 SW2d 955 (Ark. 1952); Parks vs. Atwood, 118 Cal. App 2d 368, 251 P2d 653 (1953).

c. Failing to tell neighbor so that he may take precautions--Brown vs. Sioux City, 242 Iowa 1196, 49 NW2d 853 (1951).

d. Spreading poison so close to neighbor's fence that his cattle could reach it--Underhill vs. Motes, 158 Kan. 173 146 P2d 374 (1944).

e. Mistaking the land to be sprayed for that of another--Cross vs. Harris, 230 Ore. 398, 370 P2d 703 (1962).

2. Liability with little or almost no evidence of fault on the part of defendant:

a. Spray drifting and damaging cotton. Court held Defendant liable because he should have known of the destructive effect of the chemical and failed to confine it--Schultz vs. Harless, 271 SW2d 696 (Tex. Civ. App. 1954).

b. Damage to cotton located from 7-1/2 to 15 miles from place of application discovered 16 days after application. The negligence pleaded was that the Defendant had allowed 2,4-D to drift. Recovery was allowed against the sprayer--Pitchford Land & Cattle Company vs. King, 346 SW2d 598 (1961).

Comment. Despite this tendency toward a sort of negligence-strict liability-hybrid approach, only three jurisdictions have actually declared strict liability in crop spraying situations. They are Oregon, Loe vs. Lenhard, 227 Ore. 242, 362 P.2d 312 (1961); Oklahoma, Young vs. Darter, 363 P.2d 829 (1961); and Louisiana, applying civil law, Gotreaux vs. Gary, 232 La. 373, 94 So. 2d 293 (1957). In these cases, reasonable or even extra care does not seem to exonerate the sprayer or the spraying farmer from liability.

Damage from aerial application usually results in liability--a presumption of negligence seems to prevail.

Sanders vs. Beckwith, 283 P.2d 235 (Ariz. 1955)--Plaintiff's dairy herd was injured by DDT and benzene herachloride.

Heeb vs. Prysock, 245 SW2d 577 (Ark. 1952)--Plaintiff's cotton was damaged by 2,4-D.

Adams vs. Henning, 255 P.2d 456 (Calif. 1953)--Plaintiff's potatoes were damaged by 2,4-D.

Faire vs. Burke, 252 SW2d 289 (Mo. 1952)--Plaintiff's cotton was damaged by the drift resulting from Defendant spraying his corn.

Pendergrass vs. Lovelace, 262 P.2d 231 (N. Mex. 1953)--Plaintiff's cotton was damaged by 2,4-D.

McPherson vs. Billington, 399 SW2d 186 (Tex. 1965)--Plaintiff's hogs were killed by Defendant spraying arsenical on neighboring field to the pen.

Stull Chemical Company vs. Boggs Farmers Supply, Inc., 404 SW2d 78 (Tex. 1966); Schronk vs. Gilliam, 380 SW2d 743 (Tex. 1964)--both involved cotton damaged by 2,4-D or poisonous spray.

Recovery may be denied because of governmental immunity.

Harris vs. United States, 205 F.2d 765 (10th Cir. 1953)--Government spraying its own land--immune from liability. But see recent decision - Emelwon vs. United States, 391 F.2d 9 (5th Cir. 1968 applying Florida law).

Another kind of legal right that landowners or occupiers have is freedom from water pollution. The law, by court decisions, is reasonably well developed in this area but variations exist in different parts of the country. A general discussion of the general principles follows:

Water Pollution as an Invasion of a Property Right. Among the rights one acquires when he takes title to land is the right to have any body of water within or bounding that land continue to exist in a condition of purity and free from any improper contamination or pollution. This is a property right one acquires in land, and as such it has been successfully asserted in private actions against water polluters.

This right to pure water is not an absolute one, however. The courts have held that the right to pure water is subject to the right of other owners to use the stream to a reasonable extent. Thus, not every use of water which diminishes its quality gives rise to a cause of action.

Pollution is in no way justified by the fact that the stream may already be contaminated or that others are similarly polluting the same stream. These factors may, however, affect the damages recoverable.

Water Pollution as a Nuisance. The law of nuisances provides the private individual with a remedy for water pollution on a tort theory. Courts have defined "nuisance" to include "...everything that endangers life or health, gives offense to the senses, violates the law of decency, or obstructs the reasonable and comfortable use of property." However, nuisance law has divided itself into two general subareas: private nuisances and public nuisances.

Water pollution falls easily into the category of public nuisances. But the general rule allows only publicly brought suits against those creating or maintaining a public nuisance such as the pollution of a stream. An exception usually made, however, is to allow an individual to bring a private suit in such an instance, if he can show some special damage to himself of a different kind than that suffered by the public at large.

Whenever a public nuisance is found to exist, the state has a right to relief without the necessity of proving special damages since by definition, damage to the public is presumed. Suits to abate such nuisances are usually filed by the state's attorney or the Attorney General in the name of the "people."

Damages. If wrongful pollution is found to exist and the injured party can show actual monetary loss as a result of pollution, he can nearly always recover actual damages. Proof must show that the damages proximately resulted from the pollution shown, but the fact that those damages may be difficult to ascertain will not bar recovery.

Injunction. Injunction often is the more appropriate remedy where the pollution is of a continuing nature. A court-issued injunction may restrain someone from doing an unlawful act or, in appropriate cases, it may order him to perform an act in which case it would be a mandatory injunction.

Though historically, injunctions were available only when money damages were an inadequate remedy, most cases have held that injunctions are available in cases where invasions of water-use rights result in an otherwise continuing nuisance.

When an injunction is appropriate, it may be had concurrently with damages. The two remedies are not exclusive and thus an injured party may sue for either or both remedies.

D. Effects of Herbicide Laws on the Environment

It seems obvious that existing laws place restraints on sellers and users of pesticides and that environmental factors are now considered in setting standards and establishing classifications. This is not to say the environment was completely ignored before but the emphasis was on fraud, adulteration, and proper labeling. The onus was on people to read and use products for appropriate purposes and according to directions.

A sudden awareness of our environmental problems brought about a shift of some responsibility from the individual to government. For example, federal laws and regulations require a consideration of possible injury to the environment before a pesticide can be registered. Most of the state laws studied allow an investigation of the composition, uses and effects of pesticides before registering. Further, continuous surveillance often is required and a pesticide which creates an undue hazard to man or the environment may be removed from the market. This kind of economic harshness is found only in the most recent laws and court action may be required for complete condemnation of a pesticide, but the trend in this direction is clear. The sale and marketing processes for pesticides must now contend with people and their environment.

Just as dramatic has been the adoption by some states of registration requirements for dealers and applicators, and making all government agencies subject to these Acts. Further, pesticides have been classified, usually by regulations, according to their toxicity, resistance to degradation and impact on the environment. Special use permits are then required for the application of the highly toxic and hard or persistant type of pesticides.

Enforcement of these laws is most important and there could be weaknesses in some of the states under study because authority and some discretion for criminal prosecution is vested in the many county or district attorneys. However, the state registration procedure has proven to be reasonably effective and the number of serious violators for referral to local units may be small.

On the other side of the pesticide fence lies the restraints of a militia of laws and regulations on water and air pollution and on environmental quality. The federal government can prod states into action with money for planning and facility improvements, technical assistance, and quality standards. The Congressional mandate, at least by law, if not by adequate funding, clearly requires an improvement in the condition of the environment. The federal administrative machinery is in position for forceful action, but the EPA still struggles from the effects of conglomeration.

Water and air pollution laws in the states under study are still a bit thin although a few recent amendments have added to definitions of contaminants and created Pollution Commissions or Councils to assist or substitute for the Departments of Public Health. It appears that most of these states are beginning to take water and air pollution problems more seriously and are establishing additional offices for monitoring and enforcement.

Considering the traditionally slow pace for obtaining change in laws that impinge on economic and individual freedoms, the legislative and Congressional response to pesticide and pollution problems has been phenomenal. One can pick holes in existing laws and regulations, particularly those not updated, and complain that more and stronger laws are needed; but on the whole, the record is positive, and it appears that fresh efforts are being made in these states to pass additional laws favoring the environment.

E. Changes in Laws Recommended for Adequate Environmental Protection

In the vast open spaces of the states studied it seems almost surprising that environmental quality could be a problem. Yet all of these states register pesticides and license applicators; most of them have special laws on weed control; and at least four of the six states regulate water and/or air pollution. The more recent laws (e.g., Montana's Pesticide Law) contain repeated references to the environment and its protection.

Federal laws comprehensively cover water and air pollution, but there is a gap in pesticide use regulation. Congress is presently considering H.R. 10729 which is intended to correct this deficiency.

If the states wish to review their laws and regulations with environmental protection as one of the primary objectives, the following points should be considered.

1. Pesticide Laws. In general, pesticide laws should contain provisions for pesticide registration for dealer and applicator licensing and for adequate enforcement. Preferably all these parts should be contained in a single law to allow one set of definitions and classifications and uniform enforcement.

a. Registration: Coordination with federal registration would be highly desirable but reserving to the state the right to impose additional restrictions to meet special needs. For example, a state may want to prescribe that instructions contain the type of applicator or restrictions on the time and place of application.

Registration provides an opportunity to classify pesticides as general and restricted, or as general, limited and restricted. Regulations should spell out the details, the use restrictions on each class and what the label and instructions must include.

A registration procedure should also allow other departments such as Health, Fish and Game, Forestry, and Pollution Agencies, to review the data on the pesticide submitted and advise the registering department, or perhaps have a vote of approval or disapproval. A technical advisory committee also could be established. The degree to which such procedures are used will depend largely on how much reliance is placed on federal registration and the unique requisites of the registering state.

A general authority to limit manufacture, restrict sale and remove restricted pesticides from the market when human or animal health or the environment are endangered, would seem desirable, but due process must be observed through a hearing procedure and appeal to the courts.

b. Dealer Licensing: If the marketing process is to be limited in any way, it is essential that pesticide dealers be licensed. This also provides an opportunity to require an examination to test the knowledge of the dealer about the products being sold.

c. Applicator Licensing: The third critical part of a pesticides law is to regulate the use of pesticides. All uses should be regulated including applications by or for governmental agencies. The exemption of farmers and ranchers for the use of pesticides on their own lands has some rationale and can be controlled by requiring permits for the most toxic and persistant chemicals. Also, the Agricultural Cooperative Extension Service can be most helpful by educating their clients on proper use and sponsoring short courses on campus.

It is not quite so rational to allow a farmer or rancher to spray pesticides on his neighbor's lands without a license, but most laws now contain such an exemption. The potential damage must be assessed and weighed against the economic cost and removal of another freedom so dear to the agricultural sector.

It is the commercial applicator that must be examined for competency and then licensed periodically. The law should allow regulations to be imposed on materials, usage, restricted areas or zones, and on disposal of pesticide containers. It is highly desirable that a hearing procedure be required before use regulations are adopted.

Some laws classify applicants for a license such as principal, agent, and operator, or as applicator, operator and trainee, or some variation of these. This helps in placing legal responsibility, facilitates administrative surveillance, and requires more persons to become knowledgable about pesticides.

Newer laws also require anyone damaged from pesticides to report to the State Department that administers the Pesticides Law (usually the Department of Agriculture). From an administrative viewpoint this provision also would seem desirable.

d. Enforcement: The traditional dichotomy is a type of civil penalty through the withholding or termination of licenses, and a declaration that certain violations constitute a crime, usually a misdemeanor. As the pesticide chemical complex becomes more technical and involves many more conflicts, it appears to be timely to shift more initial responsibility and authority to the administrative side. In addition to investigations, registration and licensing, there is adequate legal precedent for administrative fines. While such penalties could be appealed to the courts, most would not be appealed, thereby relieving the court system of an increasing number of small but highly technical cases.

Usually a separate state administrative Board or Commission is established to hear complaints of violations and impose fines. This Board or Commission would have a special competence in pesticide use and perhaps in pollution control. In some states, outside of those under study for this project, pollution and environmental quality are matters of first concern to such a Board, with pesticides being of interest only when they allegedly pollute. It is suggested that such parameters may be too narrow.

e. Comment: Departments of Agriculture administer the Pesticide Laws in the states studied and perhaps this is where primary responsibility and authority should rest. But some mechanism should be employed to jointly engage the cooperation and expertise of all state departments concerned with any aspect of pesticide sales and use. An interdepartmental committee such as the working group on pesticides in Washington might be used.

2. Weed Laws. The basic Weed Laws reviewed in the states studied give authority to the County Board to declare weeds as noxious but with very little, if any, power to take direct action against violators. One state law (Colorado) provides for the appointment of a Weed Superintendent by the County Board and a tax levy to support his program. In two states (Idaho and Nevada) the state may assume some control of weeds.

Four of the states allow County Pest Control Districts, established by petitioning the County Board, except for the Montana law which automatically creates such districts for each county. All districts have authority to carry out a spraying program when a landowner is delinquent and charge him for the expense. In Montana, a county weed tax can be imposed to pay for the spraying, including a partial reimbursement to landowners.

It would seem that these various laws could be improved by the following:

a. Enabling County Boards to impose a small tax levy for weed control and to employ a Weed Control Officer.

b. Giving authority to County Boards to approve regulations on weeds and pests, but subject to review by the state with regard to the use and application of any pesticides.

c. Requiring that possible environmental damage be considered before approving countywide or local weed and pest control programs.

d. Possibly consolidating the Weed Laws with the Pest Control District Laws to provide for coordination and cooperation between the districts and the county, and also to assure compliance with state regulations on pesticide use.

3. Pollution Laws. This area of law is unraveling rapidly with substantial structural changes for administration, making it difficult to suggest changes. Unquestionably federal law is dominant at this time and some catching up is due from most states.

One difficulty pervades Federal Pollution and Pesticide Laws. Administration was transferred to the EPA from other departments. There is no basic law written just for EPA. The consequence is adjustment, some legal gaps (such as pesticide use control) and some lag in getting regulations coordinated and approved.

The splintered federal structure and recent reorganization may or may not have had a negative influence on the laws of the states under study. Two states have only very minimal laws on water pollution. Another state has a recent law only on air pollution. Three states have newer laws on pollution, two of which establish a commission and a council to assist with administration. In all cases, the cumbersome enforcement procedure and low penalties may be weak links.

It would appear that these state laws could be improved as follows:

a. Passing new laws or amending older ones to either broaden the authority of the Departments of Health for pollution control and environmental protection, or establish broad-based Natural Resource Departments with multifunctional authority. Such authority would include pollution control, water management and regulation, land use, and water and land conservation. These functions have close ties and isolated planning and separate enforcement is not the most sensible approach.

b. Buttressing the hearing and adjudicative procedure with more administrative authority for enforcement and penalties.

c. Using a substate structure where needed for regional and local administration.

d. Providing for central data collection and a mechanism for establishing priorities. An elaborate system of sharing data and techniques with all units should be an immediate goal.

The entire environmental quality system should be premised on preventive cooperative action rather than remedial edict, reserving the hard hand of power only when essential in the public interest. However, authority must be there when it is needed.

XII. CONCLUSIONS AND RECOMMENDATIONS

Based on our evaluation of the data obtained during this study, the following conclusions and recommendations are made:

A. Conclusions

1. There are an estimated 270 million acres of Western rangeland covered by sagebrush, and much of these brush-infested areas have the potential to be converted to productive grazing ranges for both livestock and game species.

2. Big sagebrush (*Artemisia tridentata*) is the most prevalent species of sagebrush, occupying about 144 million acres or 53 percent of the total sagebrush areas in the western states.

3. The herbicide, 2,4-dichlorophenoxyacetic acid (2,4-D), is the only chemical of any significance used to control sagebrush on the western rangelands.

4. The butyl or isopropyl esters of 2, 4-D are the most commonly used formulations to treat sagebrush; a low volatile ester is sometimes used when spraying near susceptible, desirable plants or when applying under critical growing conditions; the salts of 2, 4-D (Amine) are not very effective against sagebrush.

5. Diesel oil appears to be superior to water or invert emulsions as a carrier for 2, 4-D. With oil, optimum coverage can be obtained and the material will not wash off treated plants.

6. Sagebrush is most susceptible to herbicide treatment during the period of most active growth in the spring or early summer.

7. Aerial spraying is the usual method of applying herbicides on sagebrush, and most applicators attempt to deliver droplets 50 to 100 microns in size.

8. Soil erosion hazard is not increased as a result of spraying sagebrush, since erosion normally is checked by dead standing brush, undisturbed litter cover, and undisturbed soil and grasses.

9. There is evidence that soil moisture increases following the erradication of sagebrush (80-100 percent kill).

10. Data show that the snow-holding capacity is uneffected by sagebrush control in areas where drifting usually occurs, and that treated areas retain snow longer than untreated areas.

11. Increased snow-holding capacity often results in more of the melt entering the ground as underground water flow rather than as runoff in the spring. Following sagebrush control in these areas, it is sometimes possible to use springs throughout the growing season when previously the water dried up early in the year.

12. When properly applied at recommended concentrations, 2,4-D is not considered poisonous to domestic animals, fish, or game.

13. There are a number of microorganisms that can degrade 2,4-D; the herbicide does not persist in the soil, and it has no adverse effects on soil microorganisms.

14. Generally, spraying of sagebrush with 2,4-D reduces forbs in the treatment area. However, decreases in some forb species may be countered by increases in other species resulting in little net change in forb density.

15. Adequate concentrations of 2,4-D for treating sagebrush should not damage grasses, and grass production will increase after sagebrush competition is eliminated and more moisture is available.

16. Forbs and browse, including sagebrush, are important as food for various wildlife that inhabit the rangelands. Reduced growth of certain forbs on summer ranges could adversely affect antelope, sage grouse, mule deer, whitetail deer, elk, and possible moose. Removal of sagebrush on winter ranges probably would be most detrimental to sage grouse, antelope, and mule deer.

17. The use of 2,4-D for sagebrush control on the rangelands does not appear to present a hazard as a water pollutant. The herbicide does not persist in soil and the regions are very dry. Therefore, there is little opportunity for 2,4-D to be washed into the few streams and bodies of water in the sagebrush areas. Results of pesticide monitoring programs show that water samples from Western states contained concentrations of 2,4-D, when present, considerably below the amount permissible in public water supplies.

18. Although 2,4-D has been widely used for weed and brush control, poisoning by the material is rare in man. It is generally concluded that 2,4-D does not present a direct toxicity hazard to man when correctly handled or used for weed control.

19. Food crops have been found to contain insignificant amounts of 2,4-D and it is unlikely that there is any hazard to man from those sources.

20. Many methods of sagebrush control other than spraying have been employed. No one method is universally the best because sage grows under widely varied conditions. Most of the alternate control methods utilize equipment designed for other functions, are sometimes slow, are not as effective as spraying, often encourage soil erosion, and may be expensive.

21. From a study of the pesticide laws pertaining to the study area, it was clear that the laws, regulations and court decisions place substantial restraints on the production, sale and use of pesticides, and in particular, on herbicides.

22. More legal attention is being given to environmental quality protection, but with some variance between states.

23. There is an awareness of pollution problems as evidenced by the laws passed that clearly mandate a better environment.

B. Recommendations

1. To meet the demands of an ever increasing population for more livestock production, additional animal products, and larger numbers of game, sagebrush control is necessary to provide additional and more productive rangeland acreage.

2. The use of 2,4-D herbicide to control sagebrush is a practical, safe, and economical method, and it should continue to be used for range improvement in the Western states.

3. The laws concerning pesticides should be reviewed and a single law developed covering registration and dealer and applicator licensing with uniformity in definitions, hearings, enforcement, penalties, and regulations.

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